HIGH POWER LPP-EUV SOURCE WITH LONG COLLECTOR MIRROR LIFETIME FOR HIGH VOLUME SEMICONDUCTOR MANUFACTURING

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Agenda

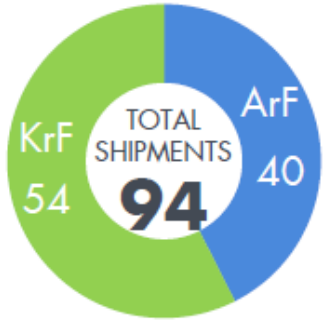
- Introduction
- HVM Ready System Performance
  - EUV Source System
  - Availability Status
- Key Component Technology update
  - Pre-pulse technology
  - Droplet generator
  - CO2 laser
  - Collector Mirror Life Extension
- Summary

INTRODUCTION

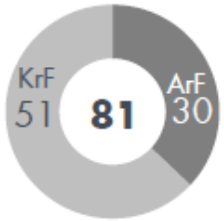
2017 Business Highlights

DUV Business

- We foresee 94-unit shipment as the projection for 2017
- Announced a new GT65A product with cutting-edge lithography light source technology and new eco-friendly solutions



2017



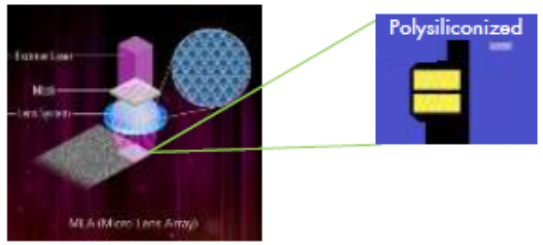
2016

EUV Business

- -0.4% per Giga-pulse of Collector mirror reflectance demonstrated
- Further scalability scenario toward 300/500W EUV power realized
- Achieved major milestone toward >80% availability on Pilot light source

FPD Business

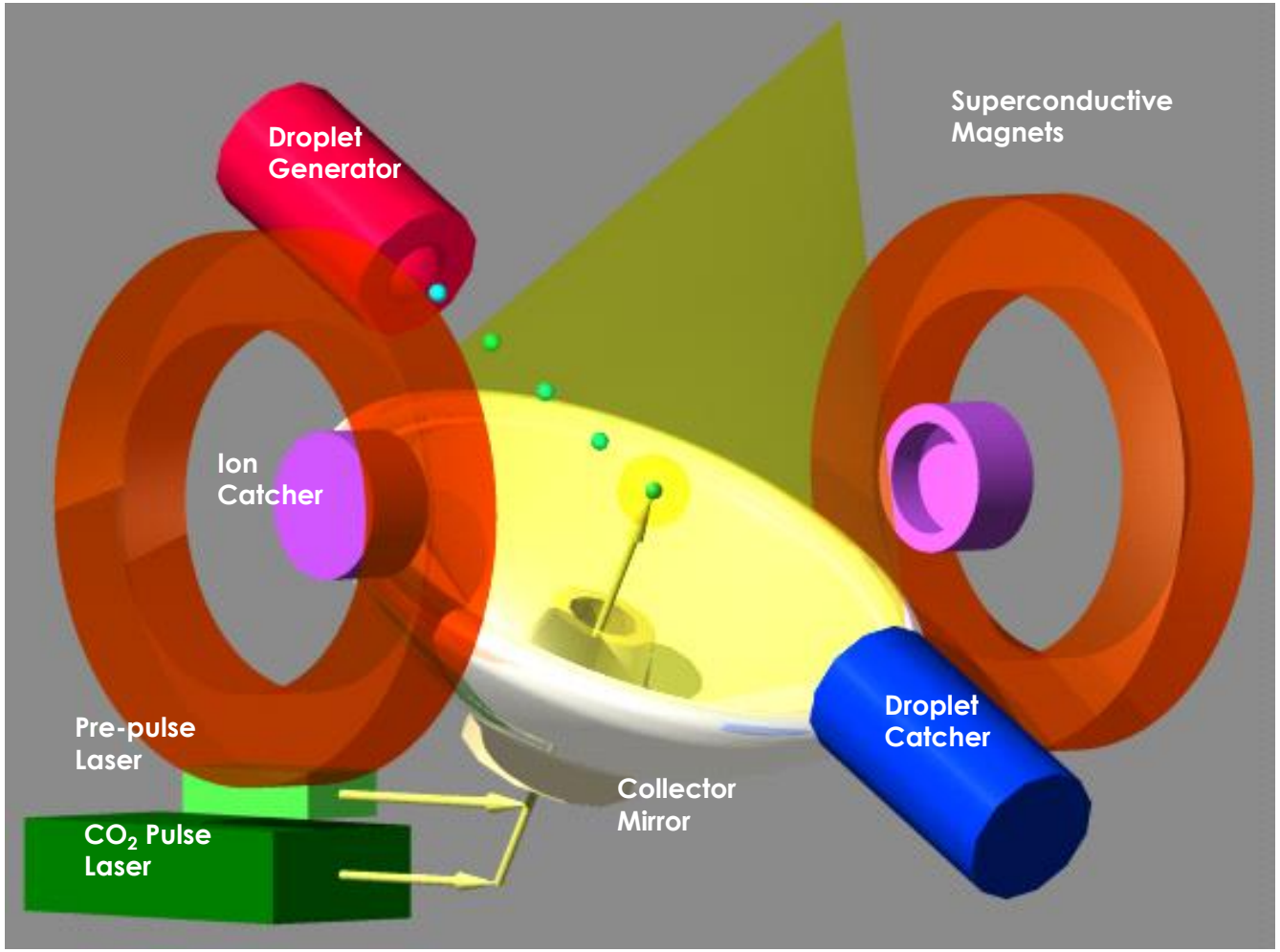
- Selective Laser Annealing system with GT600K-Integrated Released into the China market in Oct 2017
- High availability > 99.7% through Lithography experience
- Advanced maintainability, No window cleaning required
- Minimum gas usage by Gas recycling system



HVM READY SYSTEM PERFORMANCE

Gigaphoton LPP Source Concept

1. High ionization rate and CE EUV tin (Sn) plasma generated by dual-wavelength shooting via CO_2 and pre-pulse solid-state lasers
2. Hybrid CO_2 laser system with short pulse high repetition rate oscillator and commercial cw-amplifiers
3. Tin debris mitigation with a super conductive magnetic field
4. Accurate shooting control with droplet and laser beam control
5. Highly efficient out-of-band light reduction with grating structured C1 mirror



Target System Specification

		Proto#1 Proof of Concept	Proto#2 Key Technology	Pilot#1 HVM Ready
Target Performance	EUV Power	25W	>100W	**250W**
	CE	3%	> 4%	**> 5%**
	Pulse Rate	100kHz	100kHz	**100kHz**
	Output Angle	Horizontal	62°upper	**62°upper**
	Availability	~1 week	~1 week	**>80%**
Technology	Droplet Generator	20 - 25μm	< 20μm	**< 20μm**
	CO_2 Laser	5kW	20kW	**27kW**
	Pre-pulse Laser	picosecond	picosecond	**picosecond**
	Collector Mirror Lifetime	Used as development platform	10 days	**> 3 months**

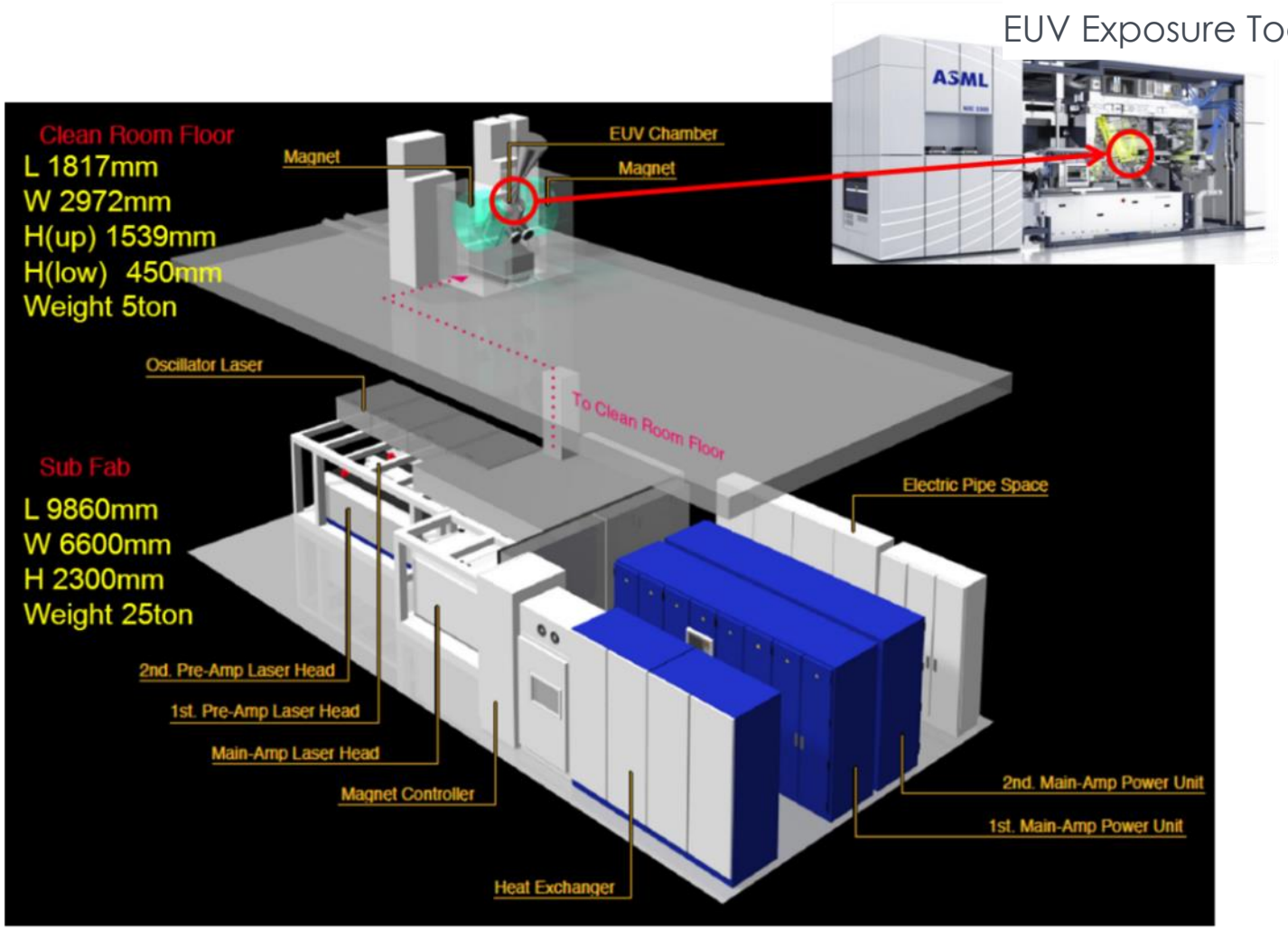
Layout of 250W EUV Light Source Pilot #1

First HVM EUV Source

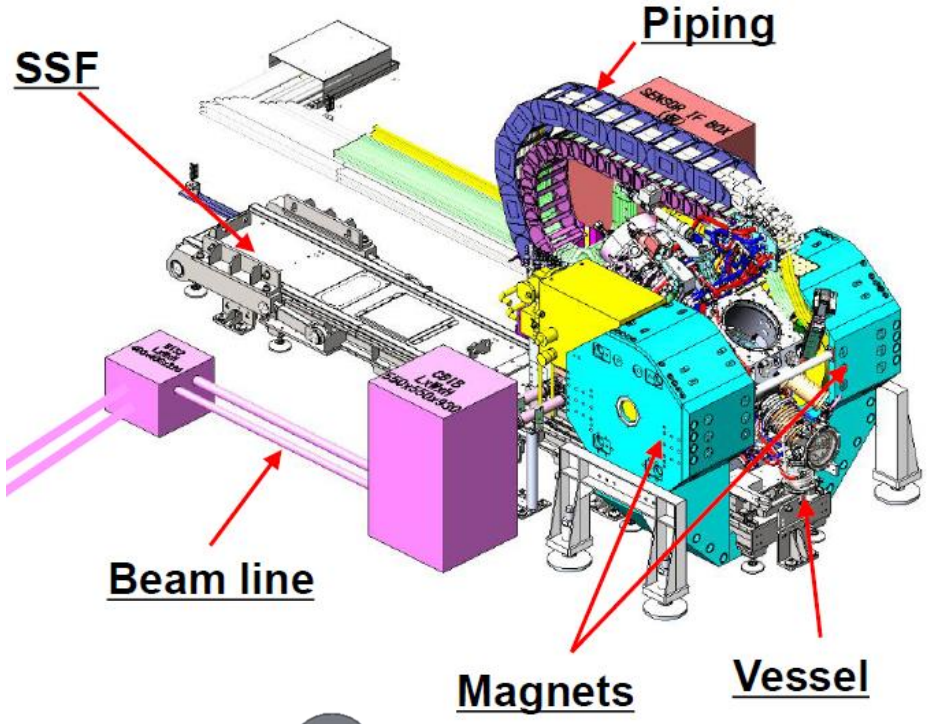
- 250W EUV source

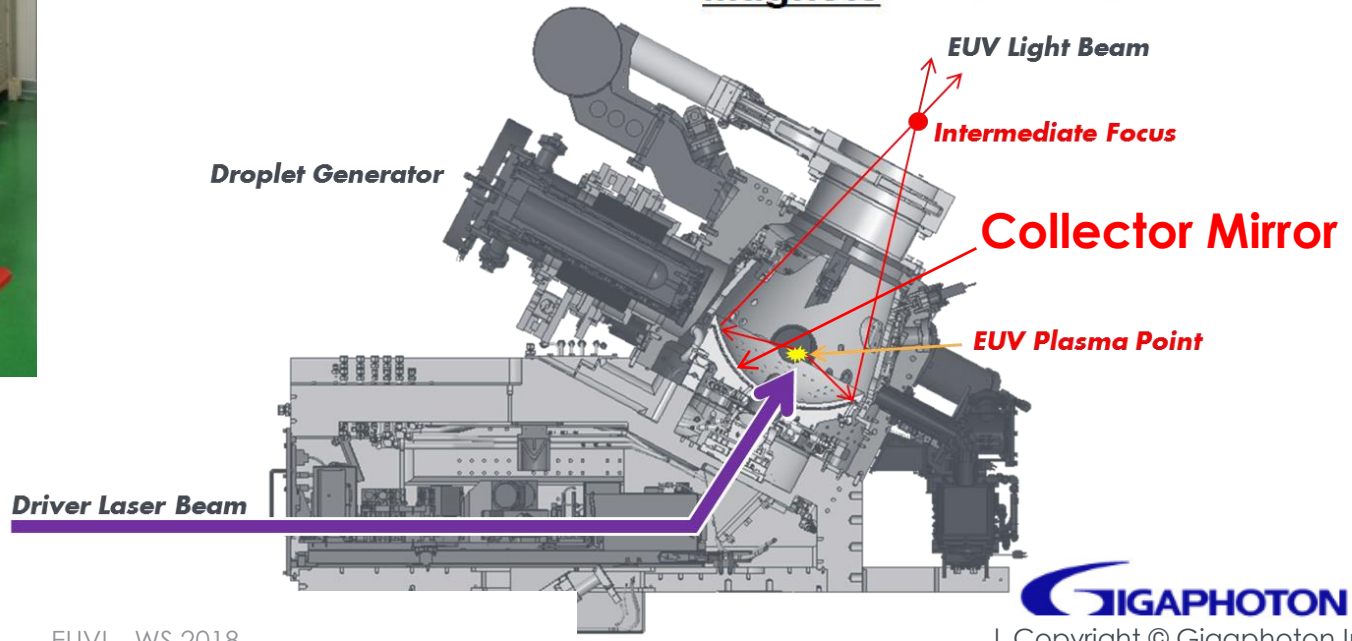
Operational specification (Target)			HVM Source
Performance	EUV Power		> 250W
	CE		> 4.0 %
	Pulse rate		100kHz
	Availability		> 80 %
Technology	Droplet generator	Droplet size	< 20mm
	CO2 laser	Power	> 20kW
	Pre-pulse laser	Pulse duration	psec
	Debris mitigation	Magnet, Etching	> 15 days (>1500Mpls)

EUV Exposure Tool



Pilot System EUV Chamber





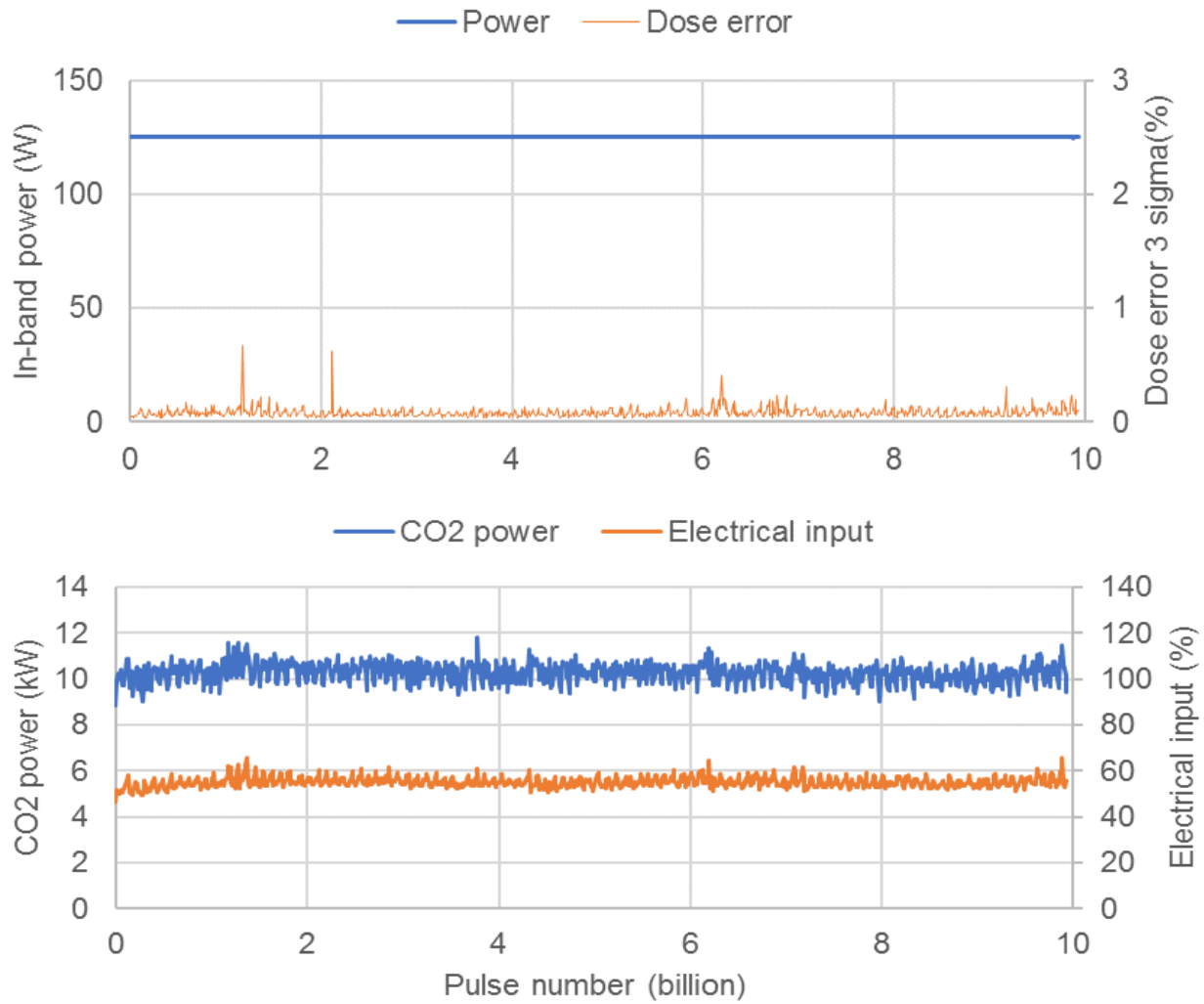
Preliminary Result

4-7. System Performance: 125W Operation Data

	Performance
Average power at IF	**125W**
Dose error (3 sigma) *1	**0.09%**
Die yield (<0.16%)*2	**96.9%**
Operation time	**28h**
Pulse Number	**10Bpls**
Duty cycle	**100%**
In-band power	**125W**
Dose margin	**30%**
Collector lifetime *3	**--**
Repetition rate	**100kHz**

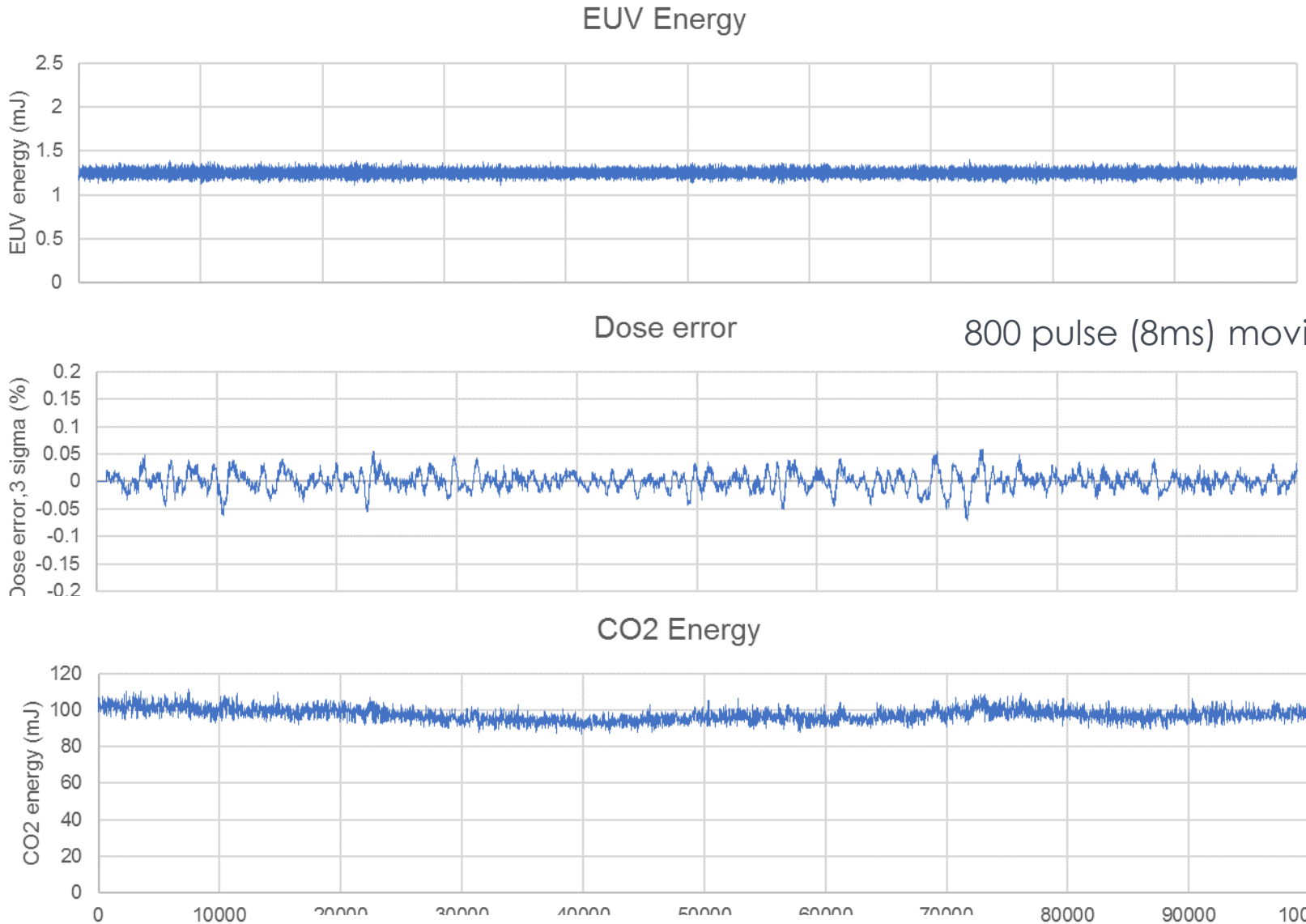
Note

*1: Dose error is defined by 800 pulse (8 ms) moving window
*2 Dose performance failure is mainly due to droplet combination failure
*3: Dummy mirror was used for investigation.



Preliminary Result

4-8. System Performance: Pulse to Pulse Operation Data

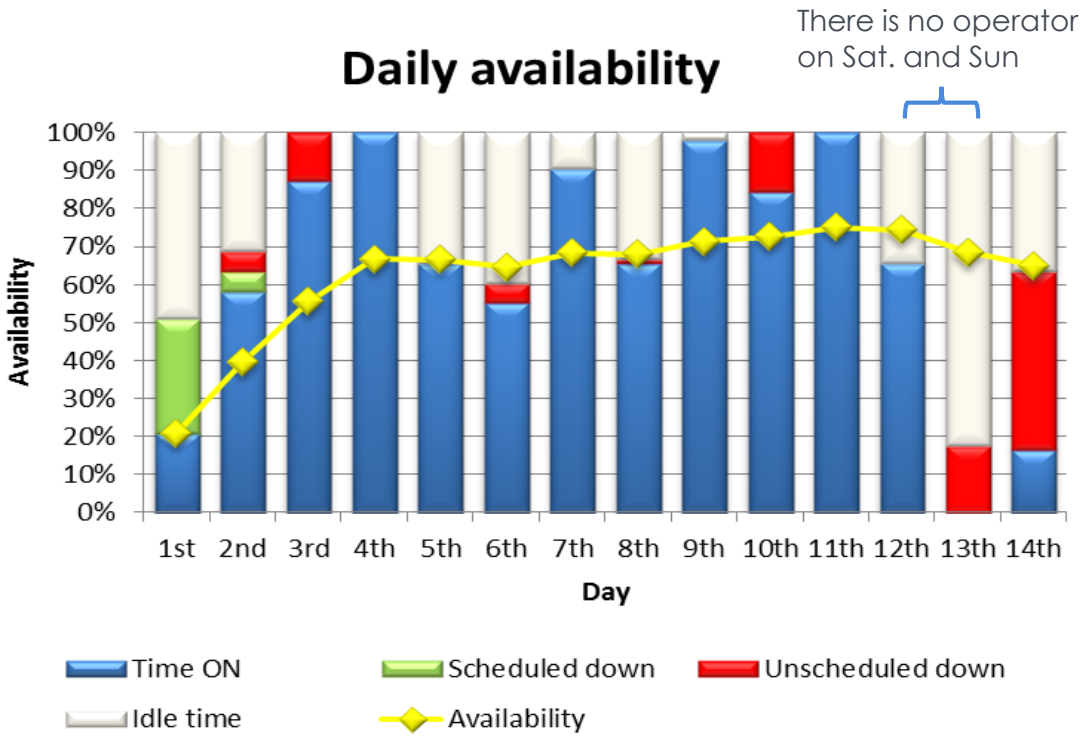


AVAILABILITY STATUS

Availability potential test

24 hour x 7 days definition
Unmanned operation between 9pm thru 8am

- 2 week availability potential test was done. Availability was 64% and idle time was 25%. Availability is potentially achievable at 89%.



Dose error : System stopped at > 2% Dose error (3 sigma) /10kpls slit and error was not recovered by automatic function
Idle time: Time for waiting operator.

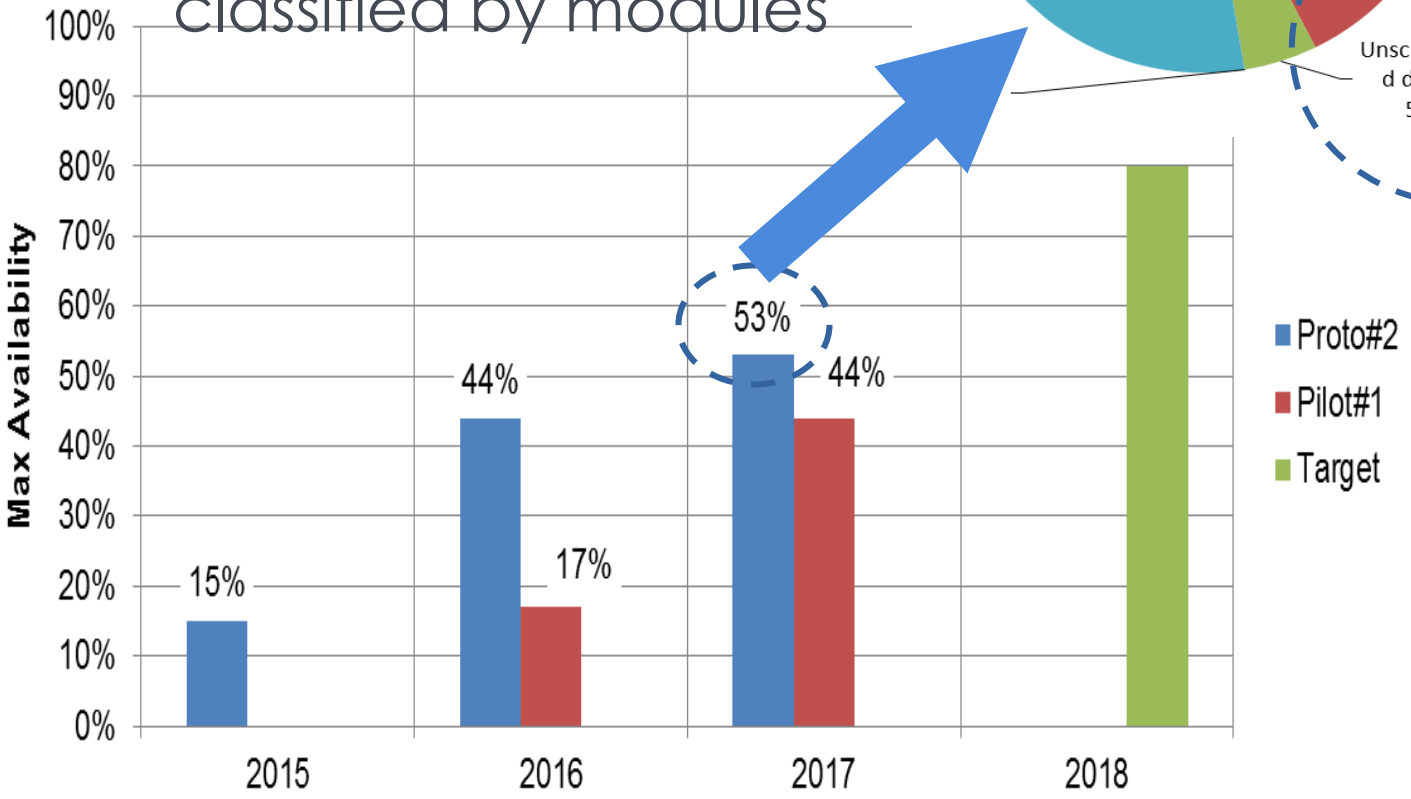
System stop event table

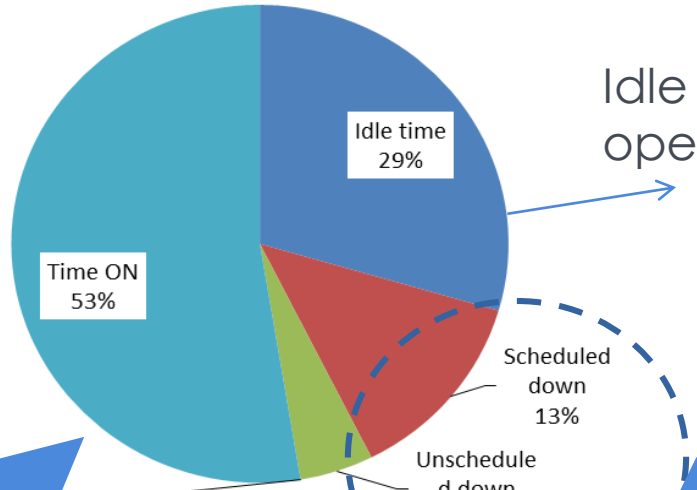
MTTR: 2.8h

Day	Event	Repair time	Root cause	Countermeasure
2	Dose Error	1.25h	25% dose margin is not sufficient	Dose margin 25% -> 28% New shooting control will be applied at Jun.
3	Sensor Error	3h	Sensor reliability	New sensor will be applied (TBD).
5	Dose Error	-	Droplet combination failure	Countermeasures will be applied at Jul.
6	Dose Error	1.25h	Shooting control algorism	Same as Day 2 countermeasure
8	Dose Error	0.25h	28% dose margin is not sufficient	Dose margin 28->35% . Same as Day 2 countermeasure.
10	Dose Error	3.75h	Droplet position instability due to particle issues.	Countermeasures are going on.
13	Dose Error	4.25h	Mirror damage in BTS(Beam transfer system) for new mirror evaluation.	Replacement to conventional mirror
14	Dose Error	11.25h		

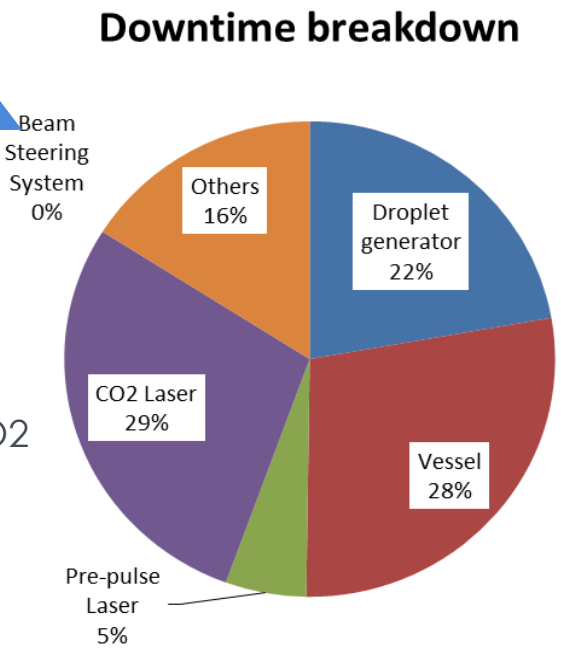
Availability Trends

- Availability improvement has been made and the challenges are classified by modules





Idle time: Time for waiting operator or service

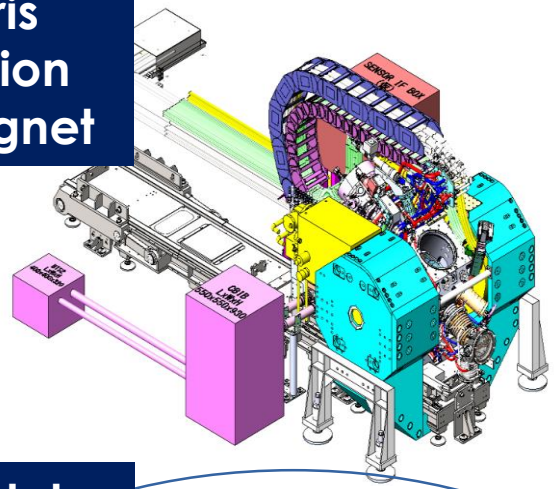


Time for gas replacement in CO2 pre-amplifier

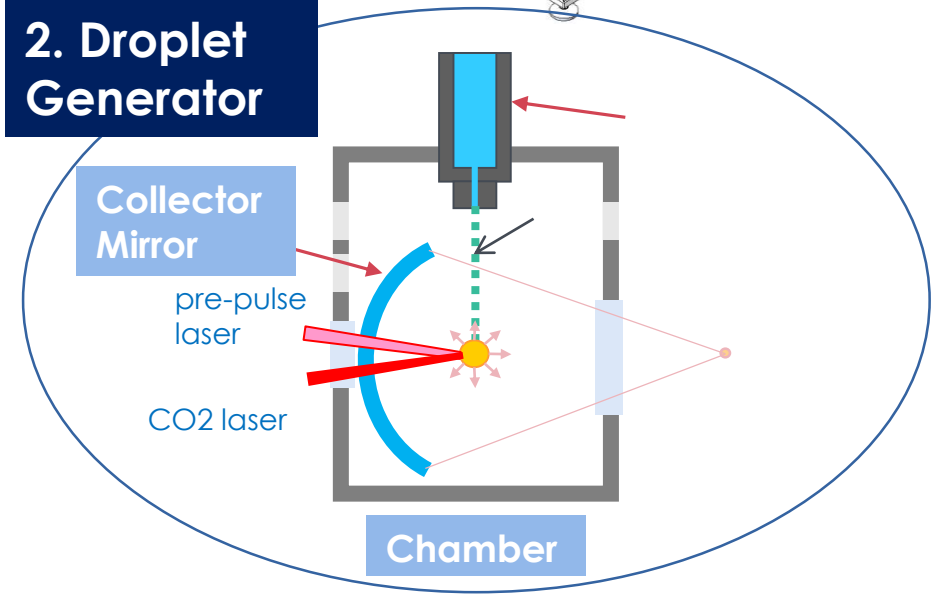
KEY COMPONENT TECHNOLOGY UPDATE

Gigaphoton EUV Technology

1. Debris Mitigation by Magnet

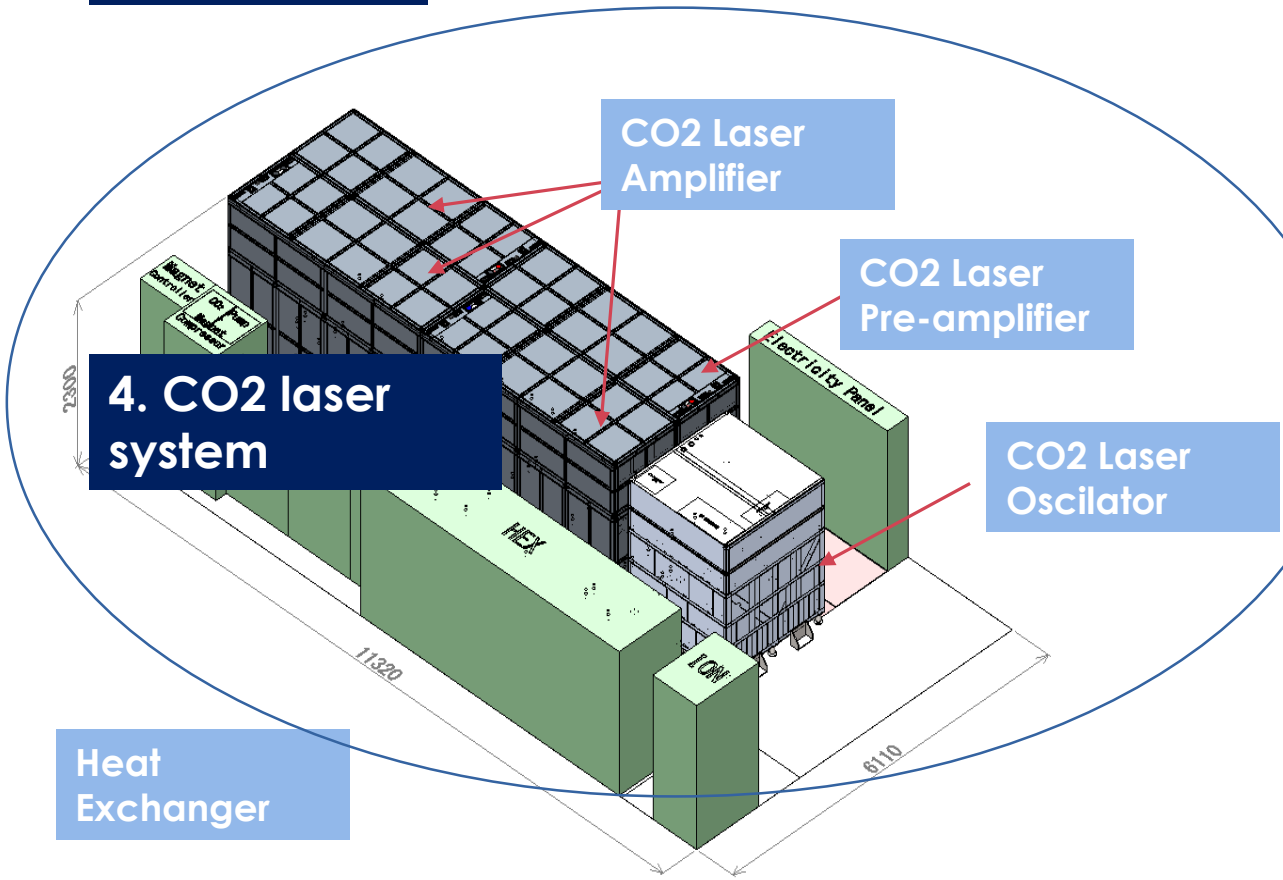


2. Droplet Generator



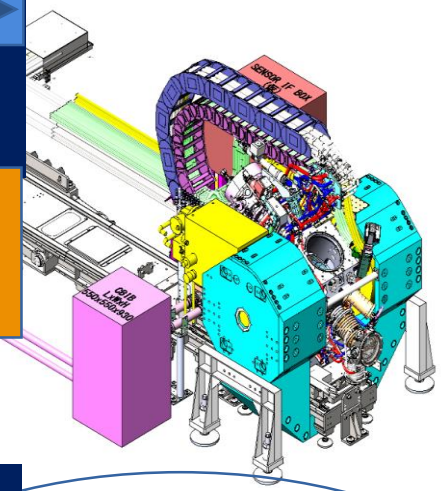
3. Pre-pulse laser

4. CO2 laser system

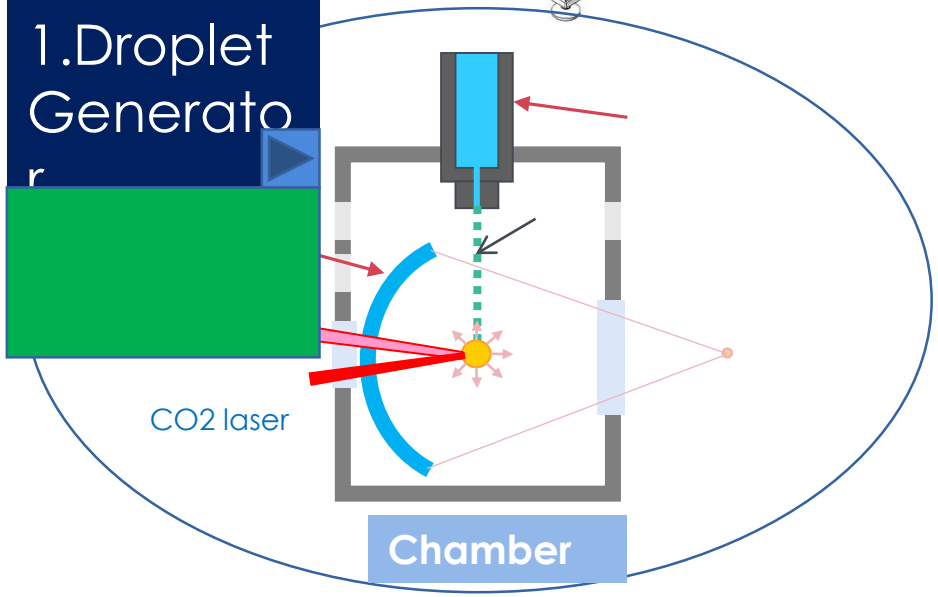


Gigaphoton EUV Technology for Lower CoO

4. Debris Mitigation by Magnet

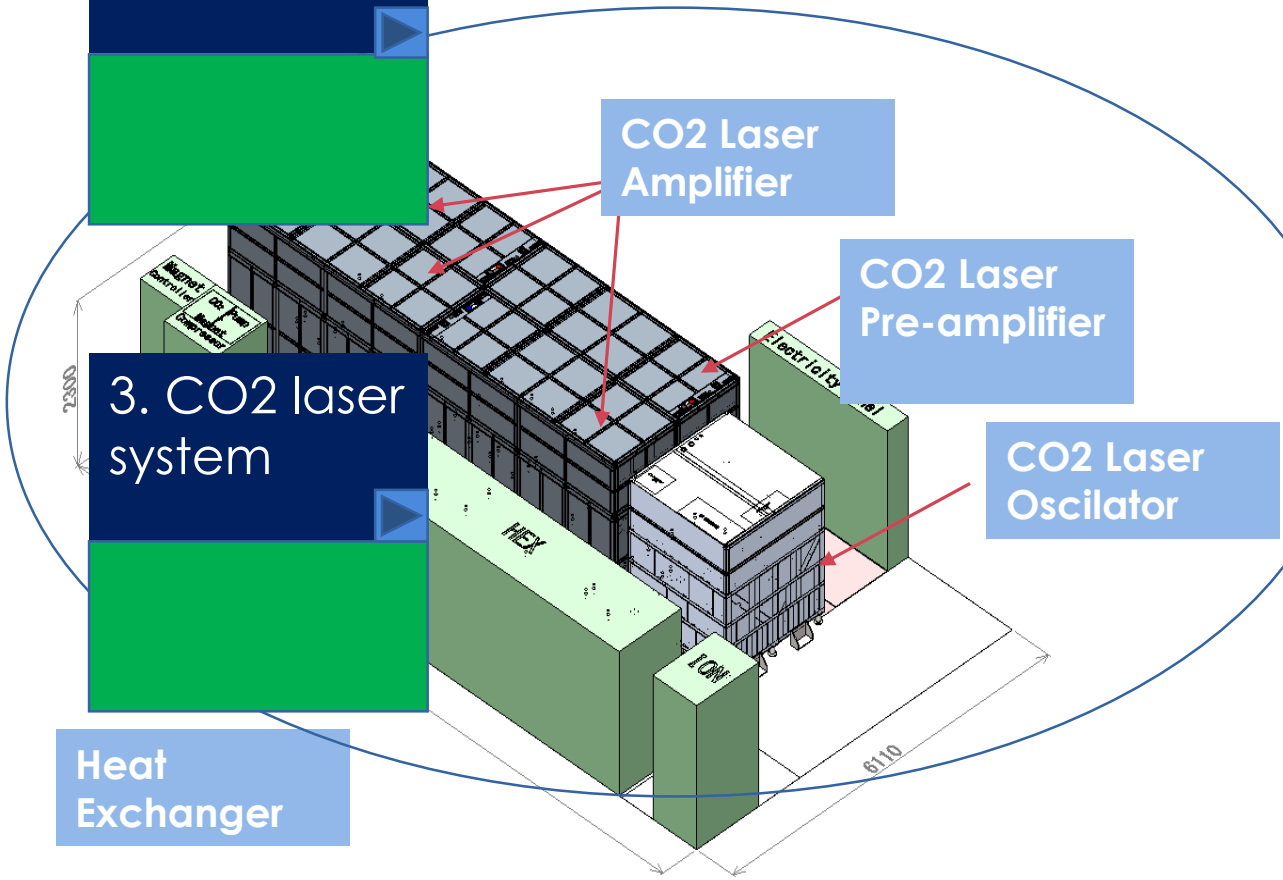


1.Droplet Generato r



2. Pre-pulse laser

3. CO2 laser system



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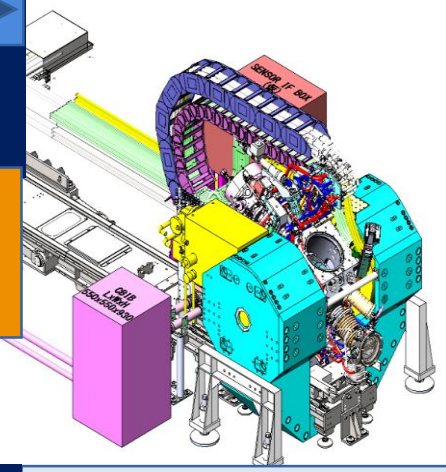
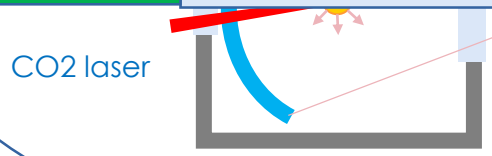


1.Droplet Generator

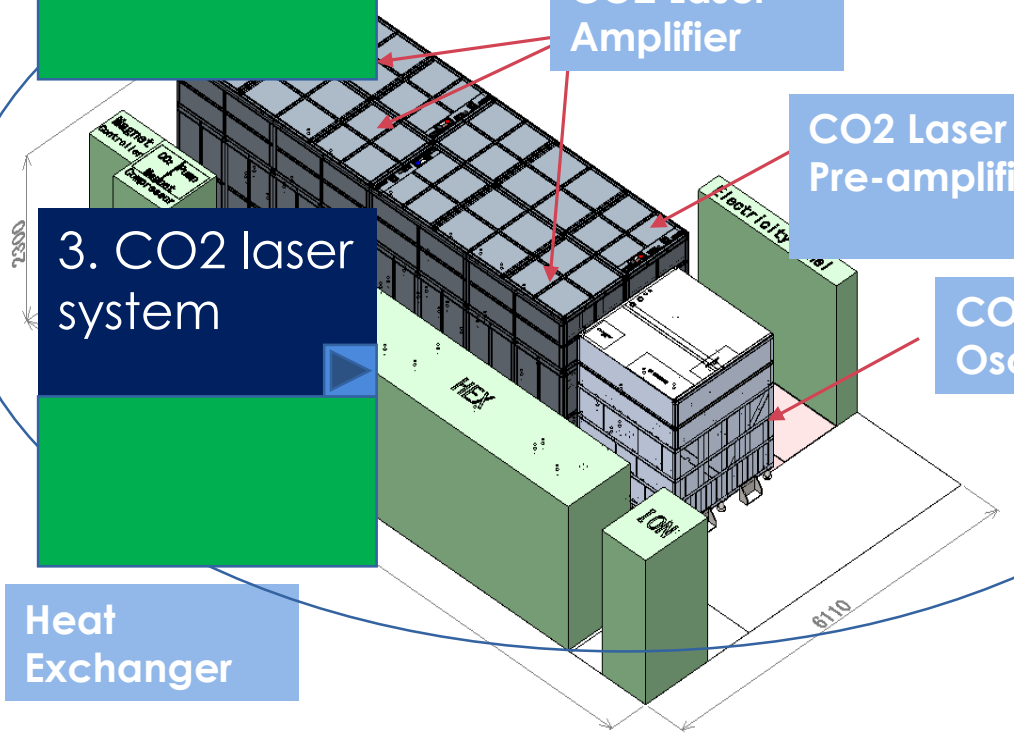
- ✓ 100kHz (2x) rep rate
- ✓ 90m/sec DL speed
- ✓ 900um droplet distance
- ✓ 20um small droplet
  =>less contamination
  =>longer DLG life



Chamber

2. Pre-pulse laser

3. CO2 laser system



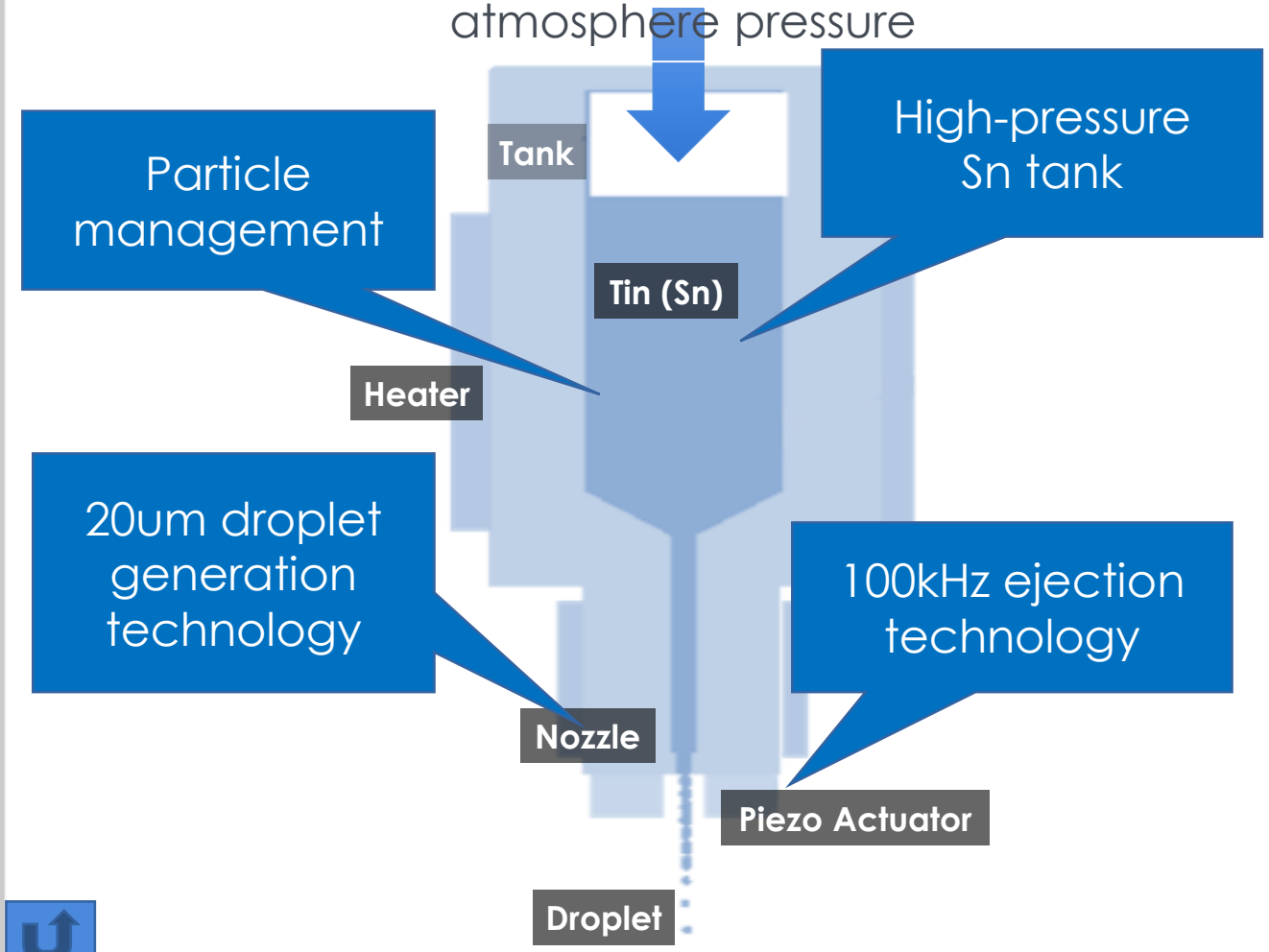
1-1. Gigaphoton EUV Technology : Droplet Generator

- Benefit: Small sized high speed droplets
  - **Less debris and 3x tin reservoir lifetime**
    due to 1/3 volume against conventional droplets
  - High speed droplets to support up to 100kHz operation,
    doubling the today's source

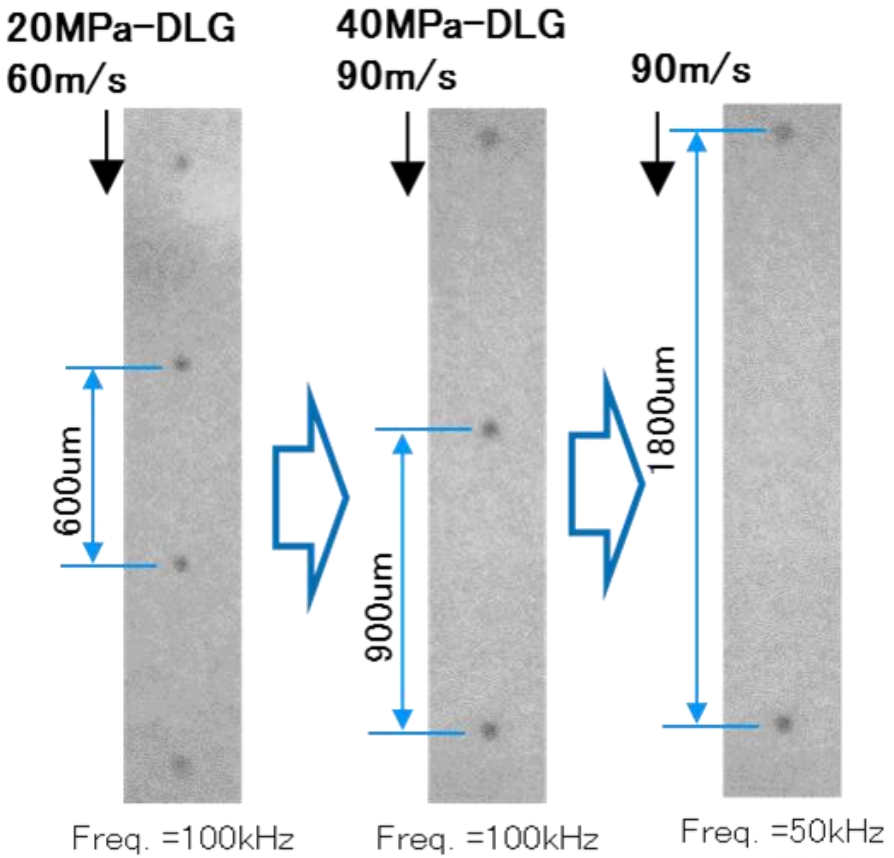
	Conventional	GPI	Remark
Droplet speed	(60m/s)	**90m/sec**	Influence from plasma is ½ vs conventional technology because the distance of 2 droplet is 1.5x
Frequency	50kHz	**100kHz**	High frequency enables to reduce one plasma energy by half to reduce Sn contamination
Droplet size	30 micron	**20 micron**	1/3 in Sn volume. Less contamination on the corrector mirror

1-2. Droplet Generator

Ar pressurized up to 400 atmosphere pressure



Diameter 20um position stability <+/- 5um



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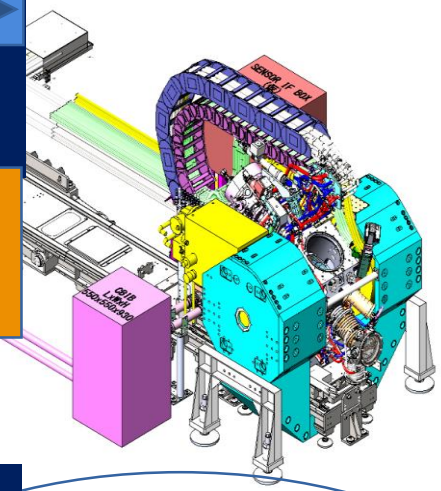
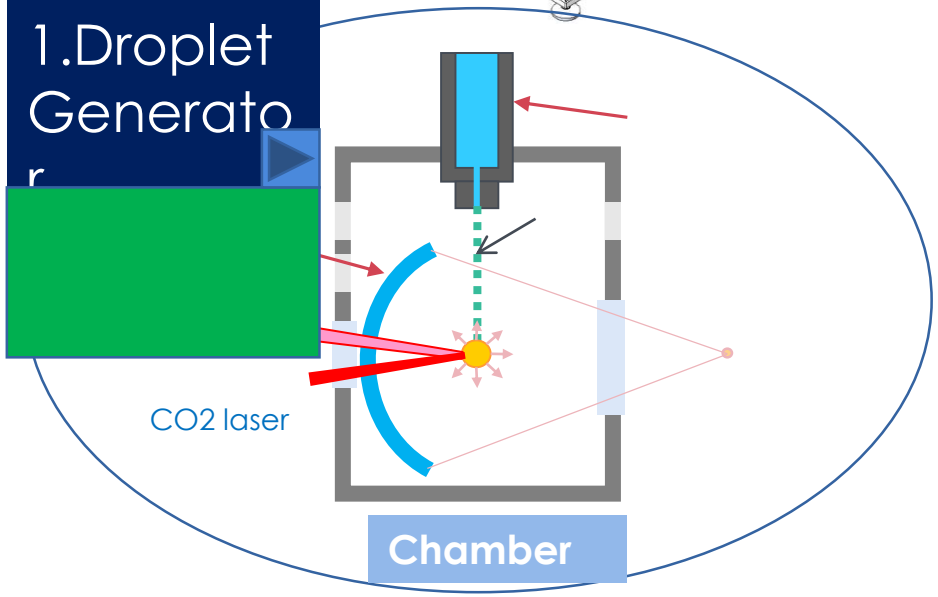
Gigaphoton EUV Technology for Lower CoO

4. Debris Mitigation by Magnet



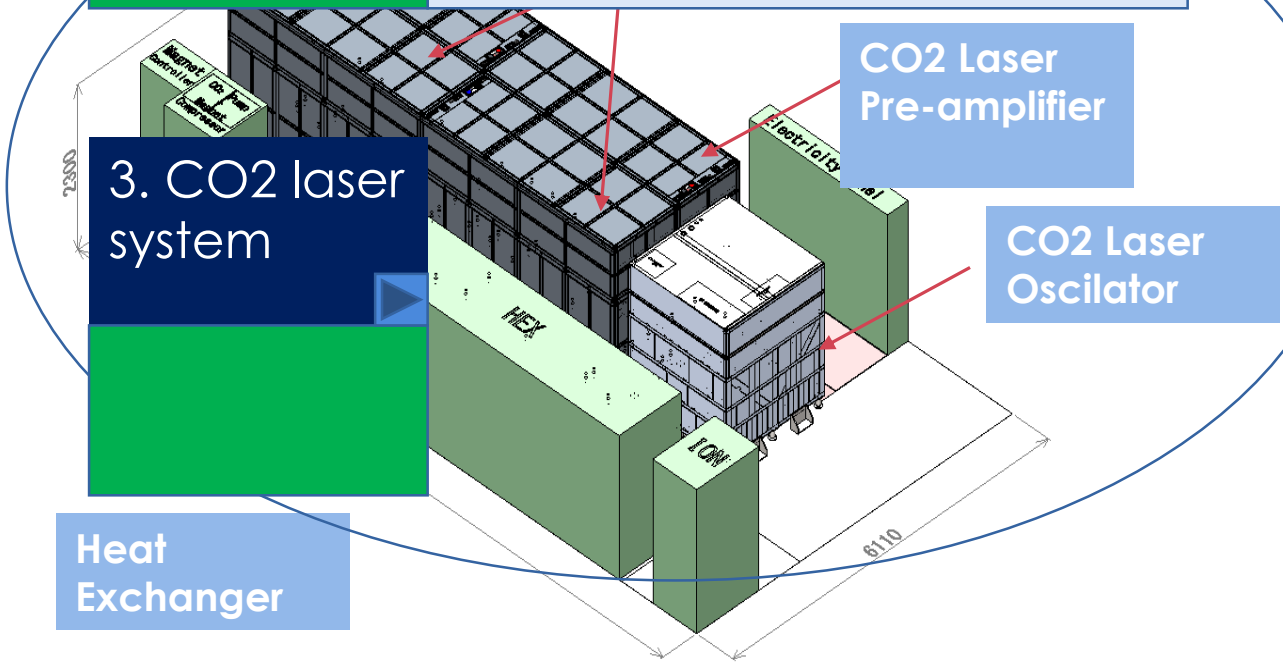
1.Droplet Generator



2. Pre-pulse laser

- ✓ Pico sec 1um pre-pulse
- ✓ Ideal dome mist
- ✓ >5% EUV CE

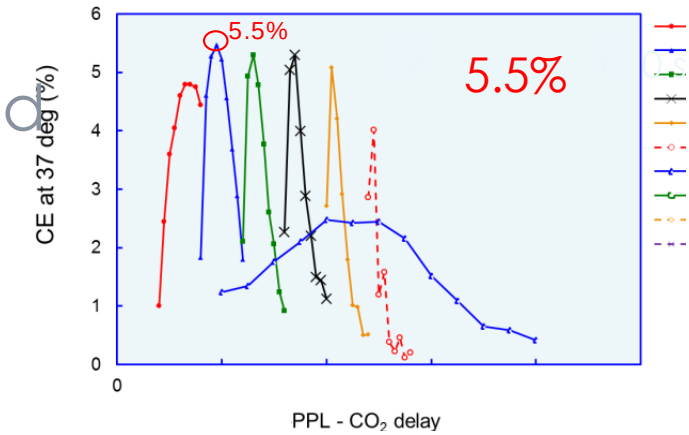
3. CO2 laser system



2-1. Gigaphoton EUV Technology : Pre-pulse technology

Benefit

- Highest **CE (Conversion Efficiency) at 5%** demonstrated
- Supports growing demand for **high power >500W**
- Run with less resources such as electricity/water/gas



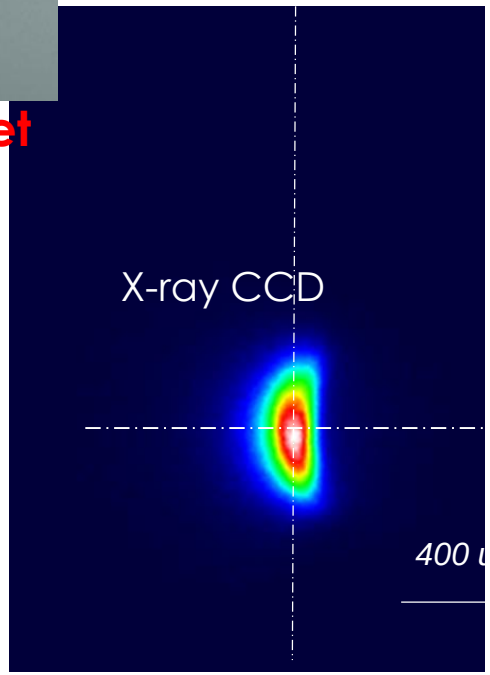
	Conventional	GPI	Remark
Pulse duration	(Nano sec)	**Pico sec**	High EUV CE >5%
WL of pre-pulse	10.6um	**1um**	Separate pre-pulse unit provide flexibility for the optimization for long term operation
Optical path	2 optical path	**Coaxial**	Pre-pulse beam with the same optical path as main CO2 beam. Shorter beam axis alignment time.

2-2. Pre-pulse technology

- Advantage of pico-second pre-pulse over nano-second

Pre-pulse (nano-second)

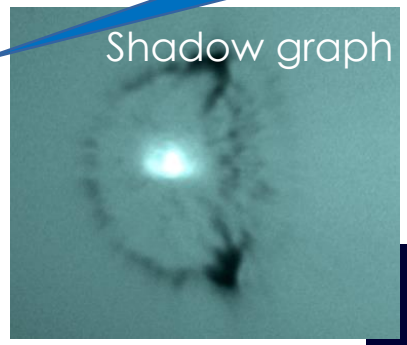
'Disk' like target



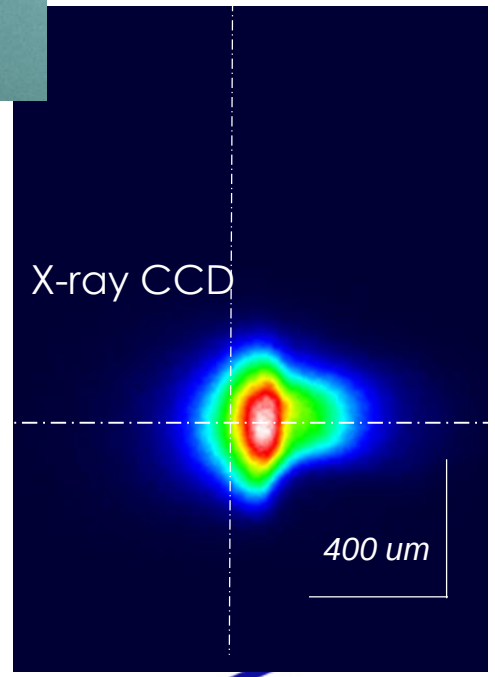
Very short pulse duration with 1um wavelength laser

Same optical path between pre-pulse and main

Pre-pulse (pico-second)

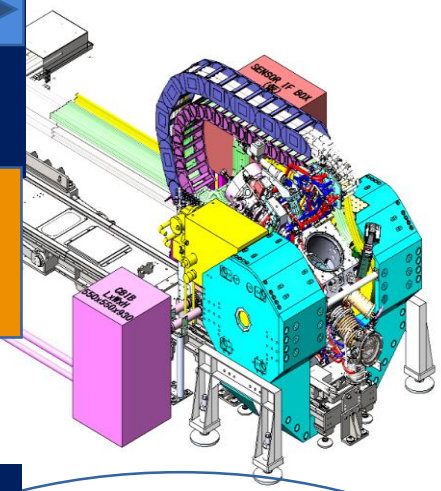


Ideal 'Dome' like target

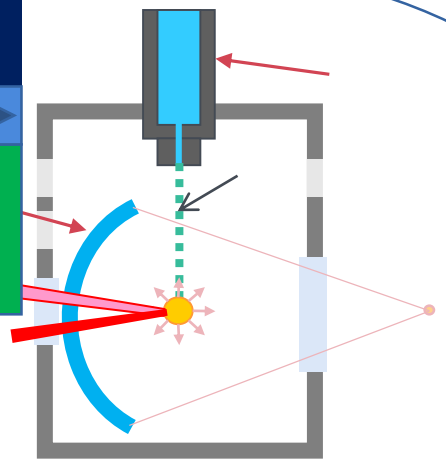


Gigaphoton EUV Technology for Lower CoO

4. Debris Mitigation by Magnet



1.Droplet Generator



2. Pre-pulse laser

3. CO2 laser system

CO2 Laser Amplifier

CO2 Laser Pre-amplifier

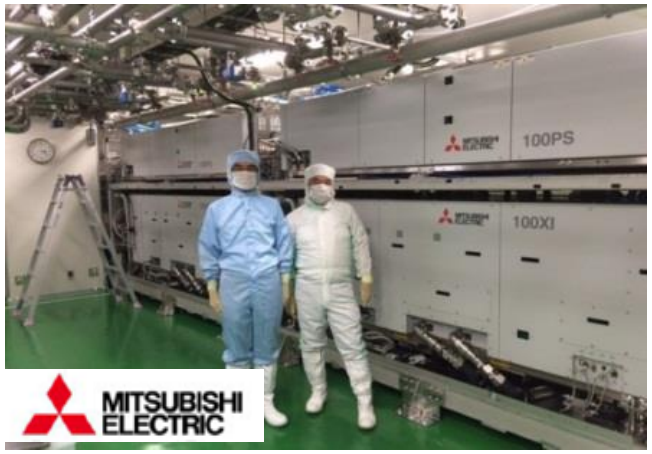
- ✓ 30% less electricity
- ✓ Uniform beam profile
  =>High CO2 CE
  =>less electricity usage
- ✓ Auto beam adjustment
  =>High availability

Heat Exchanger

3-1. Gigaphoton EUV Technology : CO_2 Lasers

Benefit

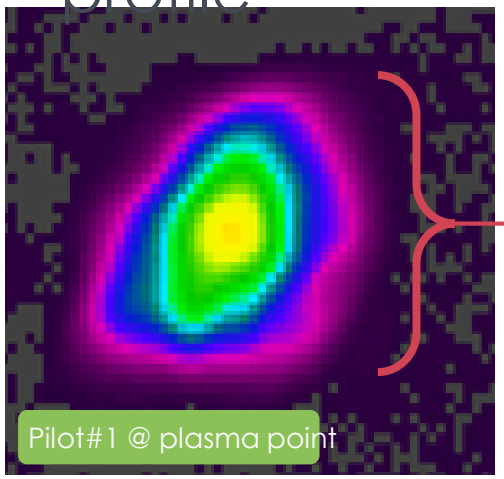
- **Excellent beam uniformity** enables efficient EUV creation
- **Short maintenance down time**
  - **Separated optical binding module design**
  - **Auto beam adjustment**
- **Efficient CO2 Laser** and **eco-friendly**



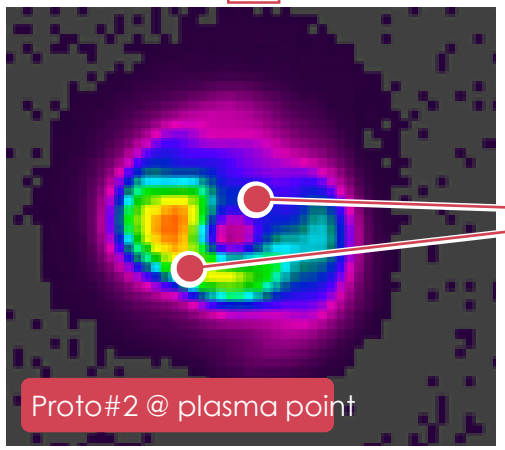
	Conventional	GPI	Remark
Beam profile uniformity	Not uniform	**Uniform**	Uniform beam profile leads higher CE.
Separate Optical Binding module	N/A	**Yes**	Minimize chamber replace time
Auto Beam adjustment	N/A	**Yes**	Keep uniform beam profile without interruption for adjustment
Power requirement	>1,200kVA	**880kVA**	30% less electricity

3-2. CO_2 Lasers : Higher EUV CE with Uniform Beam Profile

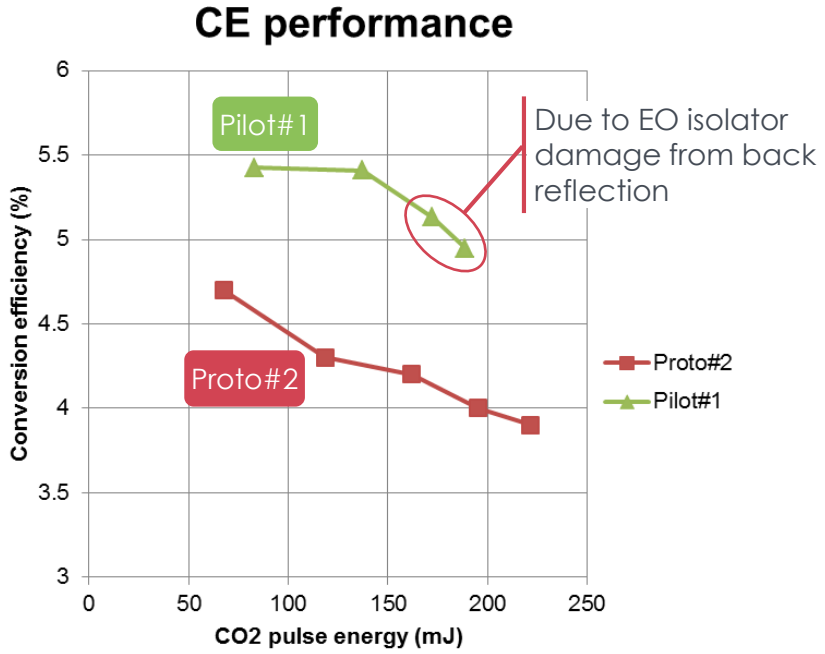
- >5% CE was achieved due to the greatly improved CO2 beam profile



Greatly improved evenness in beam profile allows for more uniform and efficient ionization of droplets – thus resulting in higher CE

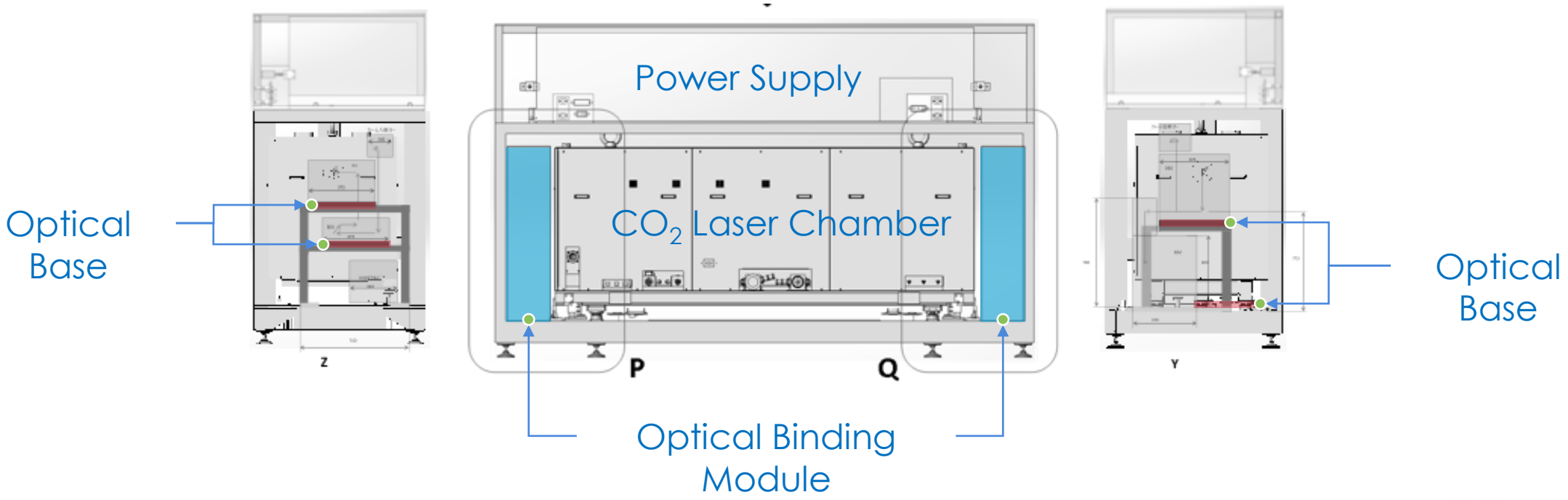


Previous CO_2 beam profile was very uneven and hence less efficient by comparison



3-3. CO2 Lasers : Separate Optical Biding Module

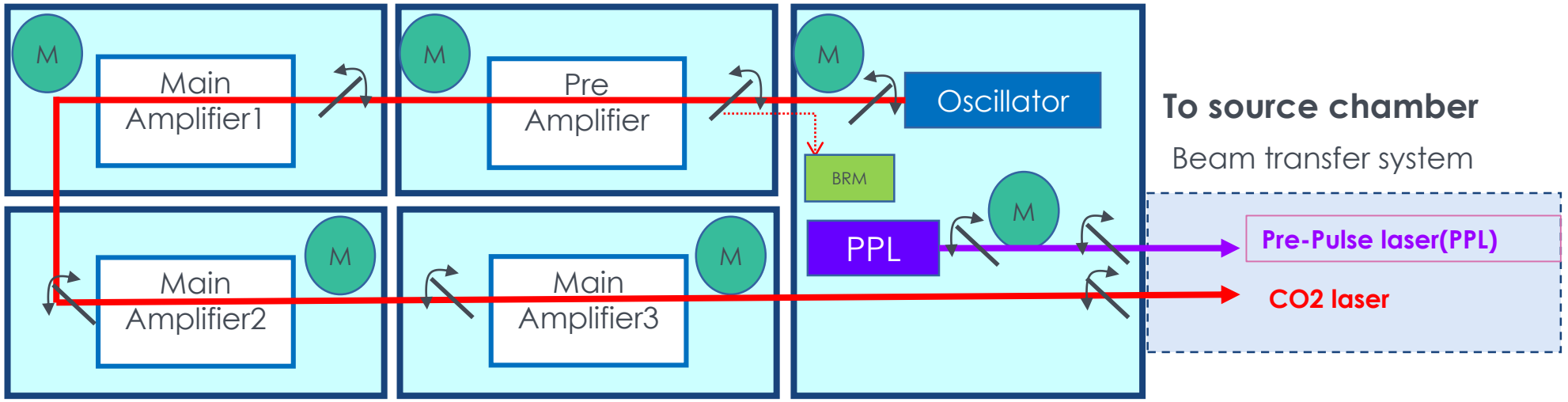
- Optical Binding Module is isolated from the CO_2 Lase Chamber and Power Supply
- Chamber replacements without axis realignment



3-4. CO_2 Lasers : Auto Beam Adjustment

- Monitor modules and beam steering modules support easy maintenance.

Easy & Stable beam axis adjustment



M

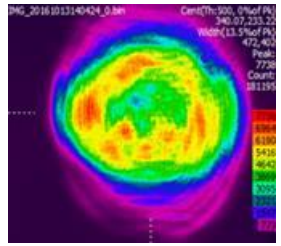
Monitor module
- ✓ Beam profile camera
- ✓ Beam divergence camera
- ✓ Pulse energy sensor
- ✓ Pulse timing sensor (Oscillator only)

Beam steering module
- ✓ XY steering mirror
- ✓ Z beam expander

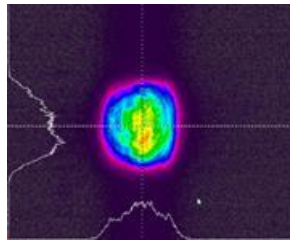
BRM

Back reflection monitor
- ✓ Power meter

CO2 laser Profile camera



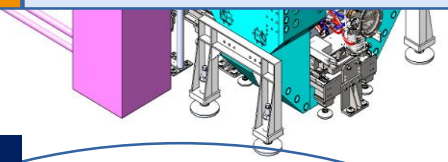
PrePulse laser Profile camera



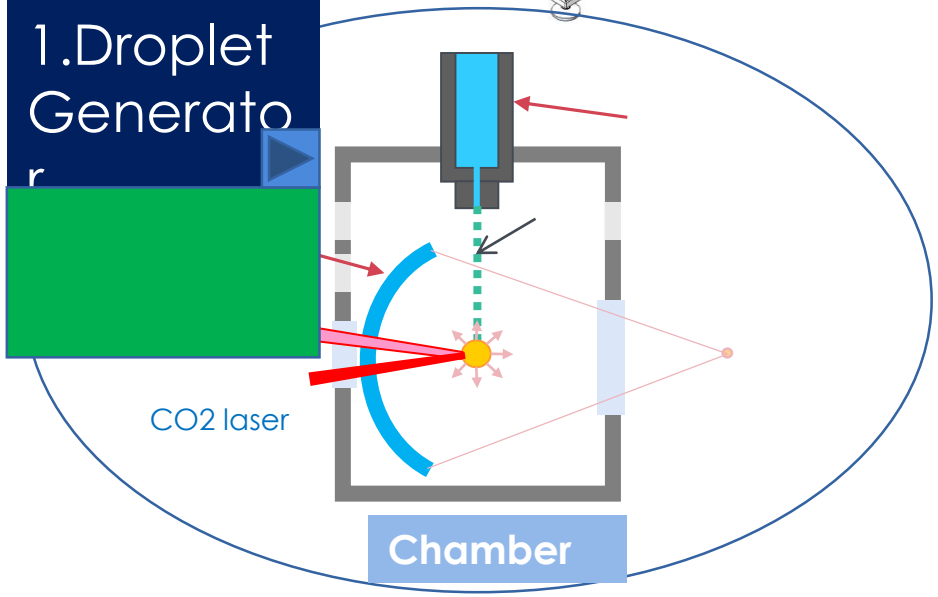
Gigaphoton EUV Technology for Lower CoO

4. Debris Mitigation by Magnet

- ✓ Magnetic field,20um small droplet, 98% Sn ionization lead less contamination
- ✓ 0.4%/G pulse @30W was achieved
- ✓ 125W mitigation test is ongoing

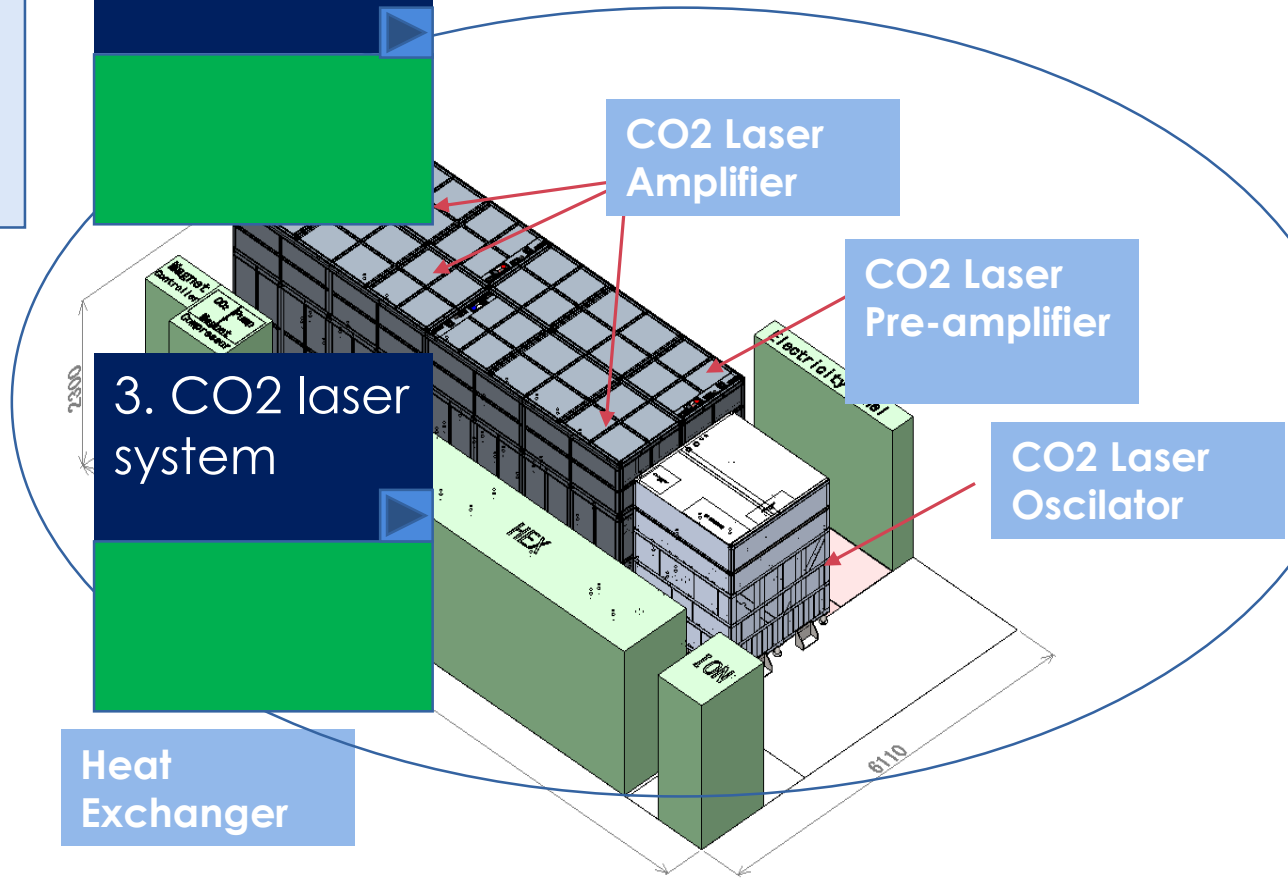


1.Droplet Generator



2. Pre-pulse laser

3. CO2 laser system



4-1. Gigaphoton EUV Technology : Debris Mitigation

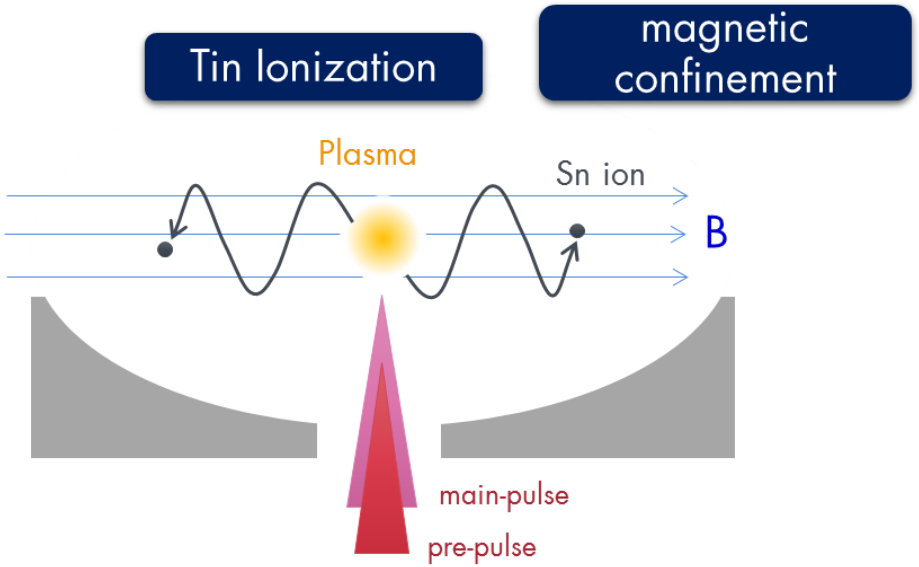
Benefit:

- High uptime and low CoO by long collector mirror lifetime
- **Magnetic mitigation** to protect the collector mirror surface from tin
- Long lifetime to minimized downtime for collector swap

	Conventional	GPI	Remark
Magnetic field mitigation technology	N/A	**1/100 # of Tin atom**	Reduces # of Sn ion which reaches collector mirror.
Smaller Sn droplet	30 micron dia.	**20 micron dia. 1/3 in volume**	Less unusable Sn for EUV emission to reduce contamination.
Hi ionization ratio of Sn 20um droplet	60%	**98%**	Less contamination on collector mirror and also less contamination inside chamber.
>125W Mitigation	Practical performance at customer site	**GPI internal test is on going**	0.4% / G pulse at 30w average power was confirmed. Mitigation test with more than 125W is ongoing.

4-2. Short-term: Etching and Dissociation Sn balance on the Mirror Surface

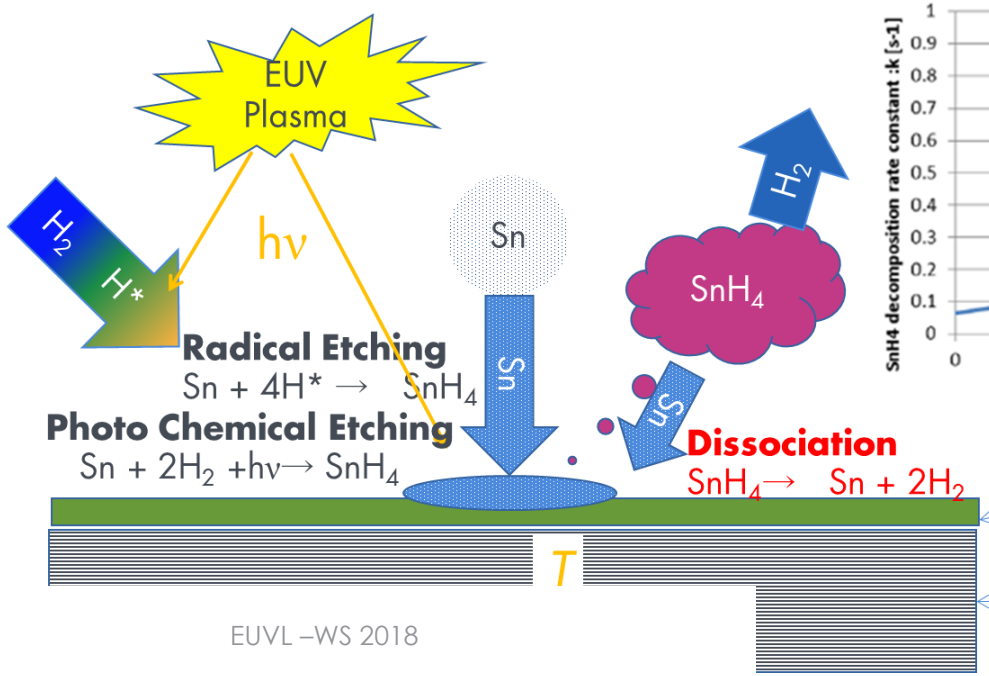
Chemical Equibrium on the Mirror Surface

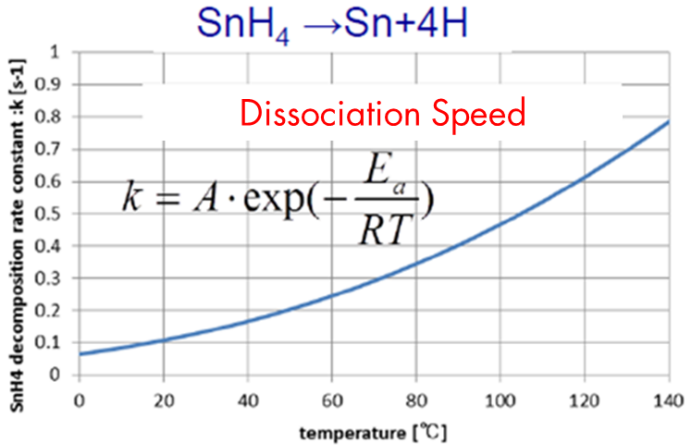


- Tin ionization & magnetic guiding
  - Tin is ionized effectively by double pulse irradiation
  - Tin ions are confined with magnetic field
  - Confined tin ions are guided and discharged from exhaust ports

- Protection & cleaning of collector with H_2 gas
  - High energy tin neutrals are decelerated by H_2 gas in order to prevent the sputtering of the coating of collector.
  - Deposited tin on the collector is etched by H radical gas*.
  - Gas flow and cooling systems for preventing decomposition of etched tin (SnH_4)

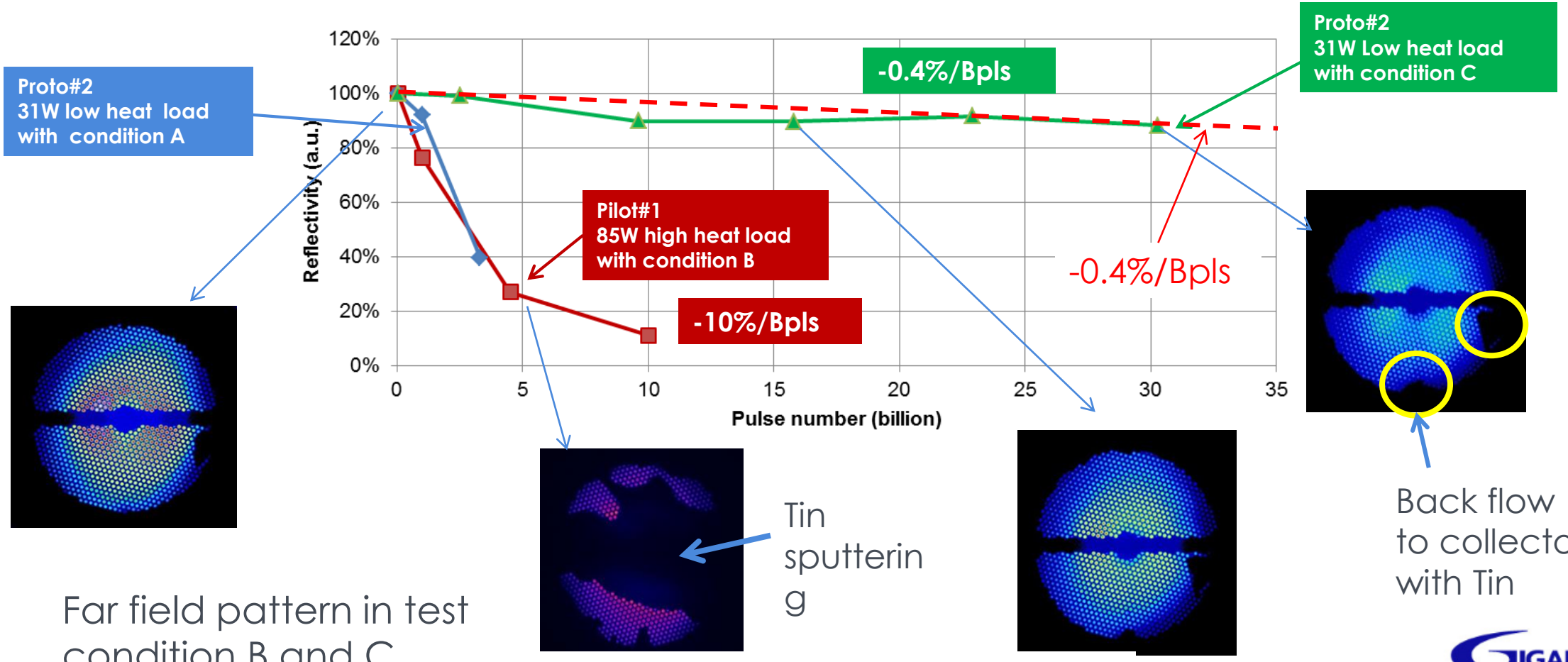
*H_2 molecules are dissociated to H radical by EUV-UV radiation from plasma.





4-3. Collector Mirror: Lifetime Status

- Power level of EUV: 95W in Burst, (= 1.9mJ x 50kHz), 33% duty cycle, 31W in average.
- Collector lifetime was improved to -0.4%/Bpls by magnetic debris mitigation technology optimization.

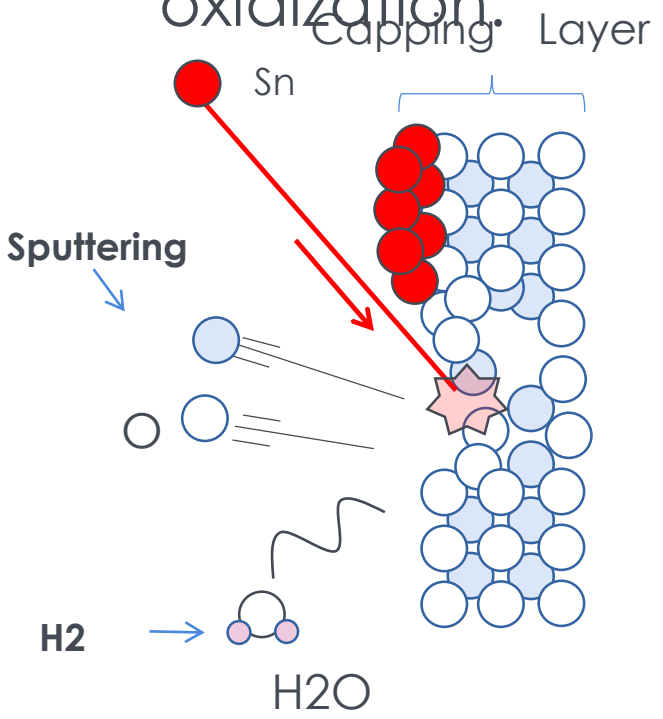


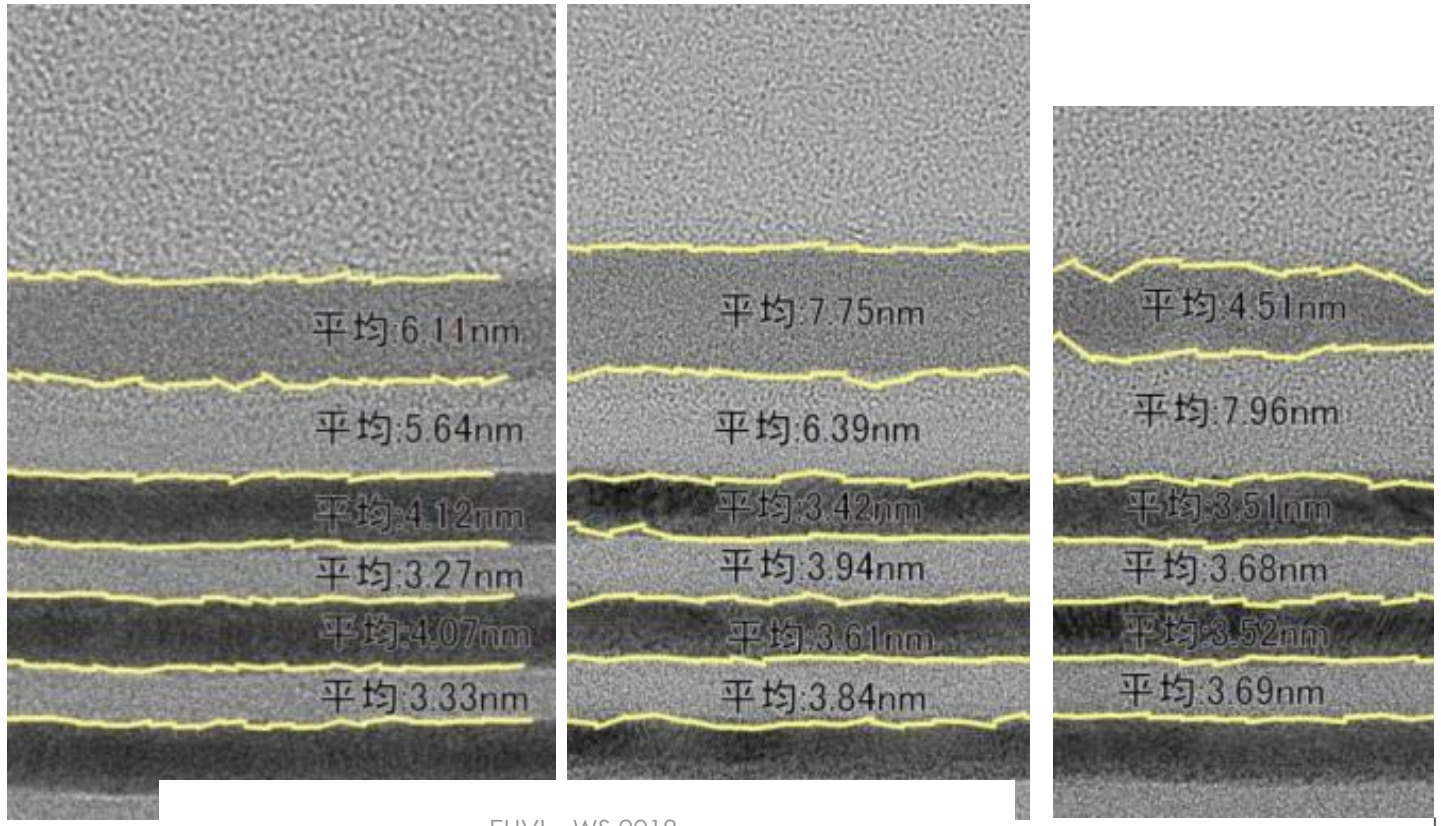
Far field pattern in test condition B and C

4-4. Long-term: Capping Layer and Multi-Layer Durability

■ Cross-section of Cap layer after long-term testing

- Thickness changes at capping layer due to sputtering.
- First Si layer become thicker and reflectance down around 30% due to oxidization.





Capping Layer

1st Si Layer

2nd Mo Layer

3rd Si Layer

4-5. Dummy Mirror Observation at 75W/125W av.

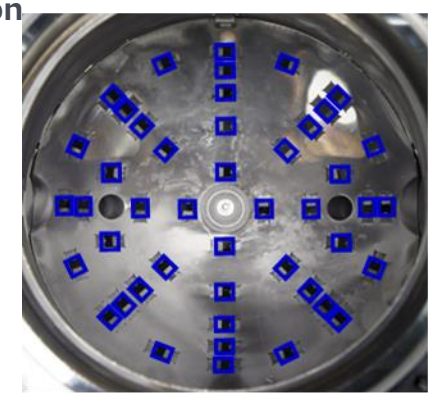
Preliminary Result

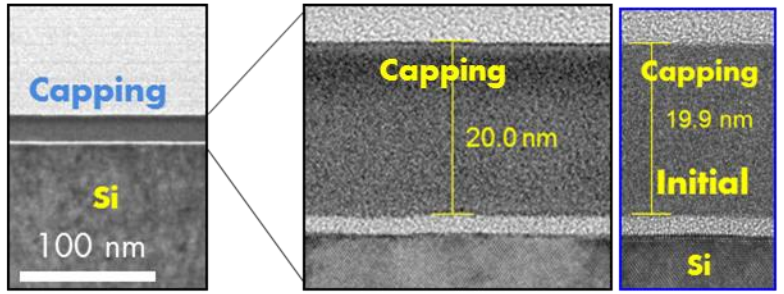
- Sputtering rate increases in high power operation.
- Tin deposition started after capping layer disappearance because Tin etching performance depend on capping layer.

No Tin deposition
Tin deposition

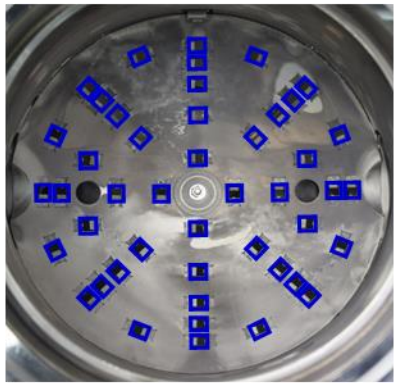
TEM of center sample

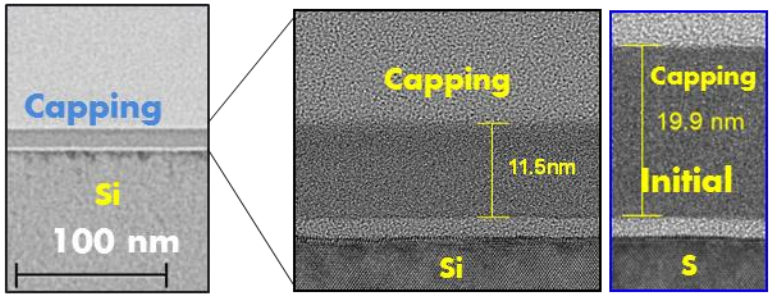
75W, 1Bpls
Sputtering rate
< 0.1nm/Bpls



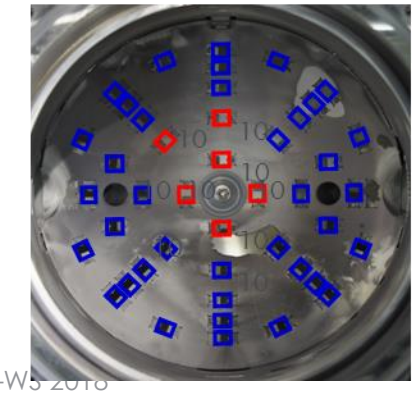


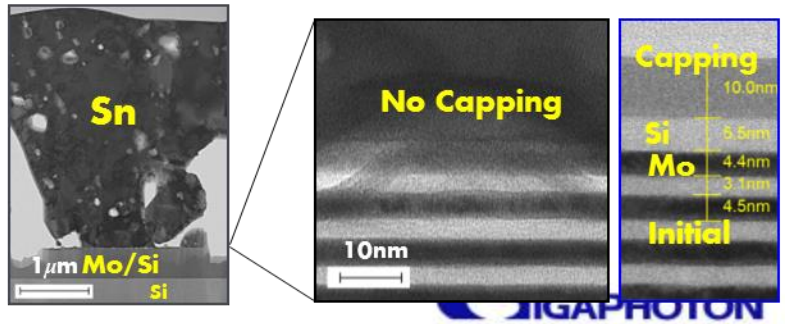
125W, 1Bpls
Sputtering rate
8.4nm/Bpls





125W, 10Bpls
Capping disappearance and Tin deposition





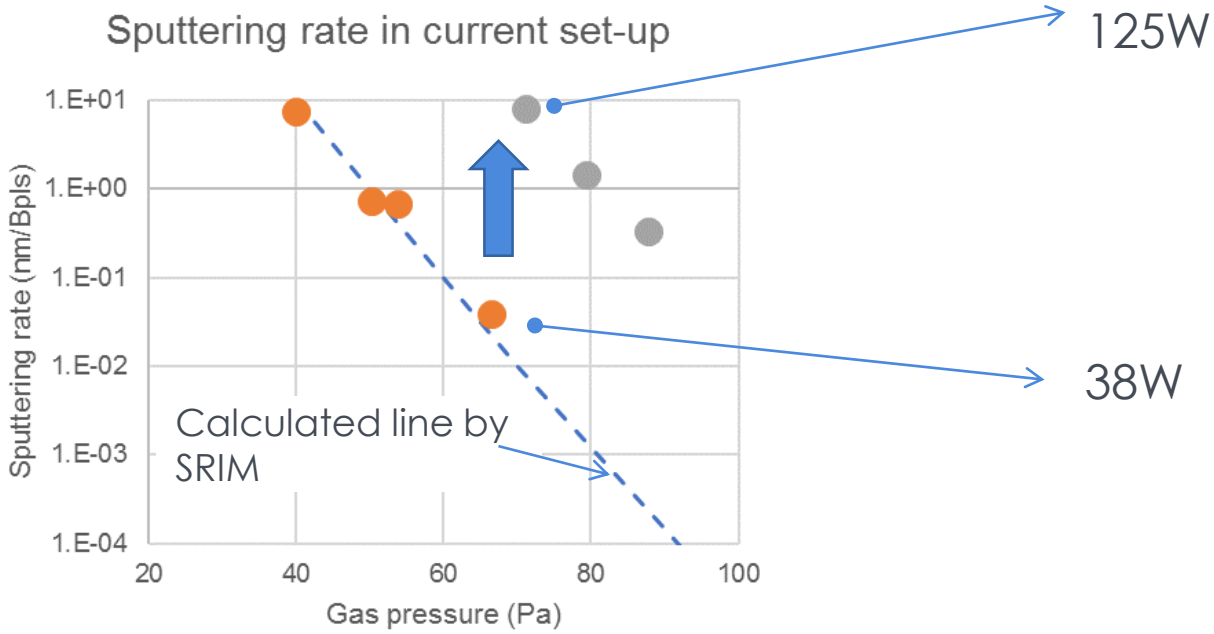
4-6. Sputtering Effect Increase by Higher Operation Power

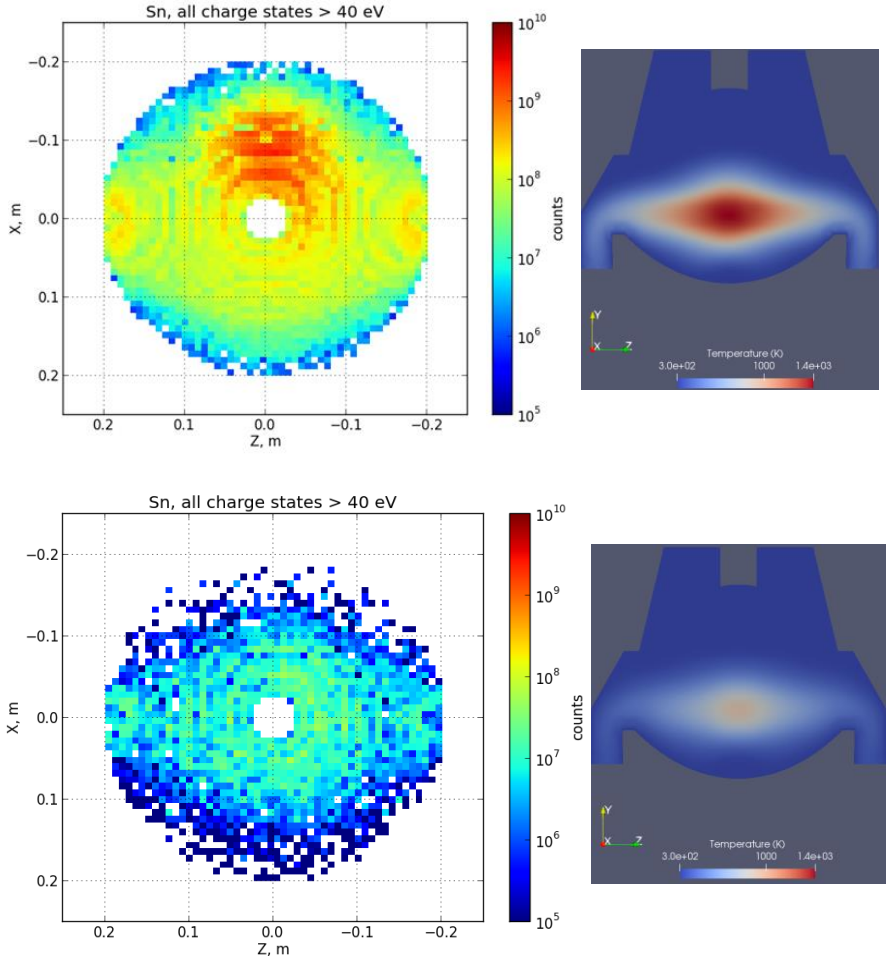
Preliminary Result

- Sputtering rate enhancement occurred by gas heating at higher output power.

<Mechanism>

Higher power → **Gas heating** → **Gas density decrease** → **Gas stopping decrease**





Tin atoms on mirror surface Temperature

EUV plasma cooling is key point of mirror lifetime extension at higher power operation

4-7. Mitigation Test Achievement and Next step

- Criteria : 0.2%/Gpls @ 1B pulses
- Achievement : Proof of concept coupon test with 75W succeeded.
  Ongoing with 125W, Flow improvement, New cap. Layer
- Next step : With real mirror, 125W degradation test for 0.2%/Gpls

Run #	180314 PRT2	180404 PRT2	1807XX PRT2	1808XX PRT2	1812XX PRT2
Power [W]	38	75	125	125	250
Mirror Contamination test coupon yield @1Bpls	OK	OK	On going	Plan Real mirror	Plan Real mirror
Sn in Chamber [a.u.]	5.68E-11	1.11E-10	2.21E-10	2.21E-10	2.21E-10
Sn on Mirror [a.u.]	8.64E-12	1.68E-11	3.36E-11	3.36E-11	3.36E-11
Duty [%]	50	100	100	100	100
Repetition [kHz]	50	50	100	100	100
IF EUV [mJ]	1.5	1.5	1.25	1.25	2.50
Flow optimization	yes	yes	Yes	Yes	Yes
Flow improvement	-	-	1st Step	Yes	Yes
New Cap. layer	-	-	Yes	Yes	Yes

SUMMARY

Summary

- Pilot#1 is up running and its demonstrates HVM capability;
  - *High conversion efficiency 5% is realized with Pre-pulse technology.*
  - *High speed (>90m/s) & small (20micron) droplet is realized.*
  - *High power CO2 laser technology is one of the important technology for HVM.*
  - *Output power 250W in-burst power @50% duty (125W ave.) several min.*
  - *Output power 113W in-burst power @75% duty (85W ave.) 143hrs.*
  - *Pilot#1 system achieved potential of 89% Availability (2weeks average).*

- ***Recent achievement for most critical challenges mirror life***
  - ***-0.2%/Gpls with 125W ave. was demonstrated at short term dummy mirror test***

- ***Next Step***
  - *-0.2%/Gpls with 125W ave. with full size mirror*
  - *>90% availability challenge with operation software enhancement*
  - *250W ave. with -0.2%/Gpls, >90% availability proof test in 2020 target*

Key Performance Status and its target

	2015	2016	**2018 Current**	**2018 End**
In-band power (Average Power)	87W (83W)	113W (111W)	**125W (125W)**	**250W**
Collector lifetime*1	No data	-10%/Bpls *3	**-0.2%/Bpls**	**-0.2%/Bpls**
Availability*2	15%	44%	**(53%)**	**> 80%**
	Proto #2			**Pilot #1**

*1, Collector lifetime estimation has been started from 2017
*2, Max availability in 4 week operation.
*3, Main issue was capping layer performance.

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2017 EUVL Workshop (Group Photo)

THANK YOU